MARINE FOG DEVELOPMENT ALONG THE WEST COAST DURING 1973 USING TRANSIENT SHIP AND COASTAL STATION OBSERVATIONS

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by

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Selected synoptic scale meteorological parameters were examined and incorporated with transient ship and coastal station observations. This appeared to be an effective technique for tracking the CCZ and identifying fog phase development.

Marine Fog Development Along the West Coast During 1973 Using Transient Ship and Coastal Station Observations

by

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ABSTRACT

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I. INTRODUCTION

The natural phenomenon of marine fog is currently the focus of much research. With reference to its causes, maintenance, dissipation and movements, marine fog forecasting is still relatively primitive when one considers the confidence and accuracy of contemporary predictions. Fleet Numerical Weather Central in Monterey, California currently forecasts an advection fog probability to be used as an alerting product to local forecasters. The fog probability forecast essentially tells the local forecaster that atmospheric conditions exist that may support fog formation. The Naval Weather Service Command (1975) cites that although the local effects cannot be accounted for, the "program gives excellent results in cases of broad-scale fog". However, Renard et al (1974) and Hale (1975) feel that Fleet Numerical's marine fog product lacks credible climatology and is not at a totally acceptable level for operational purposes.

The local effects, especially in a marine fog study along a coast such as this study, are the result of a complex interaction of synoptic and mesoscale features that must be studied and defined in an attempt to accurately predict marine fog occurrence and development.

A. OBJECTIVES

The objectives of this study are: (1) to examine the offshore atmospheric conditions relating to the formation and termination of marine fog along the central California coast for calendar year 1973 using available transient ship observations, and selected synoptic meteorological products; (2) to determine if the data from weather facilities along

the coast can successfully be applied to a proposed marine fog model to determine the extent of coastal influence and to forecast fog-related conditions offshore; and (3) to establish the credibility and sufficiency of transient ship observations used in the synoptic approach to this study.

B. BACKGROUND

The importance of research involving marine fog in an attempt to model fog for prediction purposes should not be underemphasized. Wheeler (1974) cites the strategic and economic impact of marine fog on Naval Operations and the United States Weather Service Command (1975) states that "fog probably causes more cancellations, postponements and incompletions than any other weather element". Besides the obvious effects on Naval Operations, marine fog causes similar problems for the other military services, commercial air and oceanic carriers, and to the multitude of private aircraft and pleasure boat users located in coastal areas.

Historically, marine fog research has been approached utilizing various combinations of synoptic modeling, statistical-numerical modeling, climatology, satellite photograph interpretation, and the microphysics and physics of fog occurrence. These approaches, discussed by Schrock (1976), employ as a data base six main data sources. They are from transient ship observations, coastal observations, synoptic scale analyses, satellite photographs, Ocean Weather Station ships, and scientific research cruises.

It appears to be difficult to describe the occurrence of local marine fog without first knowing the synoptic-scale picture. Although some forecasters don't believe the synoptic approach will work directly in forecasting the day-to-day variations in stratus (Rosenthal, 1972) and

associated marine fog conditions, it does reveal to the researcher and forecaster the large scale features of air mass trajectories and wind fields. In fog studies that focus on a specific area, such as this one, these large scale features supply the user with information on mesoscale features that could be applied directly to marine fog forecasting techniques. This application will be demonstrated by this study.

Probably one of the most successful synoptic marine fog models was devised by Leipper (1948) for describing the development of coastal fog around San Diego, California. Several recent coastal and marine fog studies, such as McConnell (1975), Peterson (1975), Schrock (1976) and Beardsley (1976), have applied Leipper's (1948) model to various portions of the Eastern Pacific coastal regions. A synoptic marine fog model patterned after Leipper (1948) will be proposed in a later section based on the findings of this study.

The synoptic approach was also used by Schroeder et al (1967) in discussing the effects of the Pacific Coast monsoon on the movements of marine air masses along the west coast of the United States. In general, the monsoon is a seasonal (late spring, summer and fall) feature of the general atmospheric circulation that is modified at the coastline, interacts with the sea breeze and the moving synoptic-scale systems and is restricted to a shallow layer near the surface. Although Schroeder et al (1967) does not specifically address the subject of marine fog, the study by McConnell (1975) does relate fog development to the Pacific coast monsoon phenomenon.

The two most recent studies dealing with marine and coastal fog are those of Schrock (1976) and Beardsley (1976). Their studies include a thorough review of marine fog research through the present. Since their

studies form the base for this study, their efforts will be reviewed in some detail.

Schrock chose to investigate the offshore area of the western coast of the United States out to 130° west longitude. Transient ship weather observations, supported by daily NOAA II visual satellite photographs, synoptic surface analysis maps, and National Marine Fisheries Service 15-day sea surface temperature patterns, were used to determine the offshore marine fog conditions for two separate time periods so as to coincide with two coastal fog studies covering both summer and winter marine fog development. Daily charts of fog location, sea surface temperatures, air minus sea surface temperatures, and surface trajectories (air mass history) were constructed and analyzed to determine whether or not these products supported existing synoptic models of fog formation along the California coast and to determine if the offshore marine fog conditions could be inferred from regularly available observations along the coast.

Schrock discussed the inherent difficulties in taking observations at sea and analyzed the inconsistencies found in them. Weather observers unacquainted with the present coding parameters, plus the fact that certain parameters are extremely difficult to measure (or accurately estimate), accounted for 36 percent of the marine observations used being in violation of the definitions set forth in the Federal Meteorological Handbook, No. 2 (U. S. Departments of Commerce, Defense, and Transportation, 1969), which complies with the World Meteorological Organization (WMO) regulations. A similar review of the data used in this study was conducted and will be compared to Schrock's in a later section.

In his conclusions, Schrock stated that the results obtained from his study related significantly to the coastal study by Peterson (1975), and

that the four daily charts plotted from the transient ship data and supporting products contributed to the final descriptive results. The final conclusion was that the observed sequences did indeed support existing models of fog formation processes alone the California coast.

Beardsley (1976) examined the air mass fog formation on the central California coast. From San Francisco to Monterey was chosen as the study area since good data coverage provided by coastal stations at Pillar Point, Pigeon Point, Point Pinos and the Monterey Airport were available and could be compared to the daily radiosonde sounding data taken at Oakland International Airport. The data were analyzed and graphs were produced for: the height of the inversion base; fog days at the four coastal stations; the temperature at the top of the inversion; the moisture index (the 1600 surface dewpoint temperature at Oakland minus the sea-surface temperature); the temperature index (the 0400 temperature at the top of the inversion minus the sea-surface temperature); the upwelling index (the water mass transport due to the wind stress along the coastline); Hidden Hills maximum daily temperature and minimum daily relative humidity (for determining whether a continental or marine air regime existed over a near-coast location); daily Oakland radiosonde sounding (0400 PST); and continuous surface visibilities at the four coastal stations.

Two distinct fog-related seasons were derived from the 1973 data. The summer season started in late April and lasted through October and had a much greater incidence of fog than did the winter season. During the summer, surface conditions were milder due to the location of the subtropical Pacific anticyclone. The passage of an occasional cold front across the coast tended to stall fog development in terms of hours. During the winter, frontal passages were common and resulted in delaying fog sequences for periods of days.

Data trends of the indices previously mentioned were applied to the sequences of daily fog development based on the model by Leipper (1948). The moisture index and temperature index were found to be accurate indicators of the presence of continental and marine air while the upwelling index was found to be of little value when applied on a daily basis to fog sequences.

Based on the variation of visibility and the trends of the non-diurnal indices (index values not affected by diurnal variations), a development model of summer fog was formulated. The model proceeds from clear conditions to haze, and then to the formation and advection of fog, ending with the lifting of the fog to form a stratus overcast condition. A similar model for winter fog development was not attempted due to the small number of fog cases and the disruption caused by frontal activity.

One familiar with the central California coast is aware of the fact that Oakland is separated from the ocean by a coastal mountain range and that it lies on a bay where the water surface and air temperatures are generally higher than those at sea. Since Oakland International Airport was the only location near the central California coast where radiosonde data were collected daily, Beardsley compared the Oakland data to four radiosondes taken in July at the Naval Postgraduate School in Monterey. Although the Monterey radiosonde data were acquired later in the day, it was determined that the Oakland soundings appeared to be a good approximation of the conditions over at least a portion of the central California coast, especially above 900 millibars.

Beardsley, in concluding his study, stated that a local forecaster should be able to observe phase development and predict advective fog conditions before they occur (especially in the summer) by maintaining a continuous plot of the fog indices.

This study will utilize the data taken from Beardsley (1976) in an effort to establish fog-related conditions offshore using some of the techniques demonstrated by Schrock (1976).

The term "fog" as used in this study will be as defined in the Federal Meteorological Handbook, No. 2 (1969), which is as follows:

fog - a visible aggregate of minute water particles based at the earth's surface which reduces horizontal visibility below 1,000 meters (5/8 mile).

light fog - a visible aggregate of minute water particles based at the earth's surface which reduces horizontal visibility to not less than 1,000 meters (5/8 mile) and not greater than 10 kilometers (6 miles).

This definition was considered appropriate since the data base was supposedly subjected to the same definition by the weather observer.

On the other hand, Beardsley (1976) used the visibility parameters of less than or equal to 1/2 mile for heavy fog, greater than 1/2 mile but less than or equal to 3 miles for light fog. The term haze was used for visibilities of greater than 3 miles but less than 7 miles.

The definitions of fog used in the two studies appear to be compatible. The terms "light fog" and "haze" as used by Beardsley (1976) are incorporated in the term "light fog" in this study. Since these terms imply a restriction to the visibility of the observer, they are considered in this study for comparison purposes.

II. ANALYSIS PROCEDURES

A. SELECTION OF DATA

As mentioned earlier, the main objective of this study was to examine the offshore conditions specifically related to marine fog development and to compare these conditions to those described in a coastal study by Beardsley (1976).

Beardsley chose to investigate 1973 because of the completeness of data available for the coastal locations selected for his study. However this particular year was a period of transition for the two sources of ship data, the National Climatic Center in Asheville, North Carolina, and the Climatology Section of Fleet Numerical Weather Central, Monterey, California. Data sources and data program conversions led to numerous problems which will be addressed later in this section along with the other problems encountered. The data requested from the Naval Weather Service Detachment, Asheville, North Carolina were taken from the files of the National Climatic Center which maintains a comprehensive surface marine observation file obtained from ship logs, ship weather reporting forms, published ship observations, automatic observing buoys, teletype reports and cards purchased from several foreign meteorological services (Lepore, 1976).

A rather large study area from 20°-50° north latitude and 100°-140° west longitude was selected for the credibility and sufficiency of data analyses. This area, which for the purpose of this study will be referred to as the Eastern Pacific (EASTPAC) Study Area, was selected so that

the resulting credibility analysis could be readily compared to the analysis of data in the same general area by Schrock (1976).

A second, smaller study area off the central California coast, referred to herein as the "study area", was defined in an area from approximately 35.5° to 38.5° north latitude and from the coast out to approximately 124.5° west longitude. This study area was selected so as to focus on the mesoscale features of the adjacent areas offshore and to the north and south of the area encompassing Beardsley's (1976) coastal stations. Appendix B contains a work-chart that illustrates the study area. To include the features of upwelling and the offshore extension of the study area out to 200 km (110 nm) would include the features of upwelling and circulation that are present within 150 km of the coast (Fairbridge, 1966). The area to the north was considered essential since the prevailing winds over the central California coast were from the northwest. Ship reports in this area would identify the characteristics of the marine layer flowing toward the coastal stations. The offshore area to the south of the coastal stations was included to determine if the atmospheric properties of the prevailing northwesterly winds were altered by offshore air flow from the coast. By comparing the ship observations from the southern or downwind area to those in the northern area, any change in the wind fields and/or air mass properties would be detected.

Additional supporting data sources for this study included NOAA II visual satellite photographs, National Meteorological Center (NMC) Final Analysis charts, and National Marine Fisheries Service biweekly sea surface temperature patterns, all provided by the Meteorology and Oceanography Departments at the Naval Postgraduate School, and supplemental transient surface ship marine observations obtained from Fleet Numerical Weather Central, Monterey, California.

B. DATA TREATMENT

On receipt of the magnetic data tape from Asheville, it was converted from the Tape Data Family II format to a Naval Postgraduate School tape format for use by the School's IBM-360 computer system. Printouts of the data for both the EASTPAC Study Area and the smaller study area were obtained and surveyed for initial quality and quantity problems that were readily evident. Several questionable areas were identified, and investigated. They will be reviewed later in this section. The elements of the surface marine observations printed included the position and date-time-group of the observation, wind, visibility, present weather, past weather, sea level pressure, temperature components (air, wet bulb, dew point, sea surface and air minus sea surface), cloud components (amount and type) and ship identification.

A second screening of the observations in the study area was performed to identify those reporting fog. A unique scheme developed by Renard et al (1974) and Willms (1975) was used to identify the "foggers" and to assign a fog duration.

The scheme devised by Renard et al (1974) and modified by Willms (1975), called SSR-75 (Synthesis of Synoptic Report, 1975 version) was based on a study of actual fog duration values derived from Ocean Weather Ship daily logs. These noted the beginning and ending times of fog. The SSR-75 program selects the reports identified as "foggers" by the presence of fog codes associated with visibility-weather groups and then assigns a fog duration (in hours) based on the various combinations of fog codes reported. The visibility-weather groups and related codes are those used internationally and are in accordance with the Federal Meteorological Handbook, No. 2, Synoptic Code (U. S. Departments of Commerce, Defense and Transportation, 1969).

With the computerized printouts of the data in hand, the evaluation and analysis was directed along two avenues. The first was to establish the credibility and sufficiency of the data by examining the quality and quantity of the data used. This examination included a comparison of the results from this study to those of Schrock (1976) on the coding inconsistencies associated with the visibility-weather groups from those observations reporting low visibility and/or fog at the time of or preceding the observation. This avenue will be discussed later in this section.

The second phase of data analysis, to be discussed in the results section, involved making a daily comparison of the occurrence of offshore marine fog events to those on the coast as described by Beardsley (1976). This was done by charting the number of marine observations ("non-fogger/fogger") on a daily basis and relating them to the visibility data at the coastal stations as tabulated by Beardsley for each day in 1973. A more detailed study consisting of a day-to-day analysis of all the marine observations covering four fog development sequences described by Beardsley (1976) was also conducted. The four sequences in 1973, which covered the periods 26-31 May, 19-29 April, 6-19 May and 23-30 September, exhibited both typical and atypical patterns for summer marine fog development off the central California coast.

The daily analyses of the marine observations were done on work charts similar to those in Appendix B. Conversion of Greenwich Mean Time (GMT) to Pacific Standard Time (PST) provided a convenient means to determine the time of each work chart on the basis of local night and day. The 2200 and 0400 (PST conversions from 0600 and 1200 GMT) synoptic reporting times comprised the night work-chart and the 1000 and 1600 (1800 and

0000 GMT) synoptic reports formed the day work-chart. The approximate outline of the cloud cover ascertained from the NOAA II satellite photographs was placed on the day work-chart as the times of the photographs occurred within the 0900-1100 PST (1700-1900 GMT) time period.

The elements of each marine observation plotted on the work-charts included position, wind vector (direction and speed), visibility, low cloud amount, air temperature, sea surface temperature, and fog duration (in hours) if assigned (see Appendix B).

Each sequence was then compiled in a tabular format. The location and trend of dominant pressure cells, frontal activity, and isobar alignment along the central California coast were the synoptic features selected. These were determined from the NMC Final Analyses charts. An estimate of the wind fields (direction and speed) across the central California coast was made using the reported winds, and pressure gradients. This estimate of the wind field combined with the isobar alignment was used to determine the relative strength (weak or strong) of the net air flow (marine or continental) across the coast.

A similar table was constructed for the various parameters reported by the coastal stations found in Beardsley's study. Trends in the coastal indices (moisture index, temperature index, upwelling index and Hidden Hills maximum temperature and relative humidity), and upwelling index were noted and compared to the occurrence and fluctuations of the temperature inversion as determined from Oakland's 0400 radiosonde sounding.

C. DATA ANALYSIS

When the two tabulations, offshore/synoptic and coastal/upper air, for each sequence were placed side-by-side (see Appendixes B through E),

an interesting pattern developed. The 18-29 April 1973 fog sequence (Appendix C) serves as an illustration of the observed fog development in which the northeasterly migration of the Pacific High was closely followed by coastal indices changing (moisture index, temperature index, and Hidden Hills maximum temperature increased while Hidden Hills relative humidity decreased), to indicate the influence of approaching continental (warm and dry) air towards the coast. The surface inversion was formed (as recorded by the upper air sounding from Oakland) after a lag of one day during which time the prevailing northwesterly winds offshore weakened. The coastal temperature and moisture index trends finally reach their extreme values after another lag of two days during which offshore winds decreased approaching calm conditions, or veered so as to have an easterly component.

So far, the discussion generally describes phase one (pre-inversion phase) and phase two of the fog development model (Leipper, 1948) used by Beardsley (1976). The model continues with phase three, with a reversing or cooling trend in the coastal indices, a return of weak northwesterly winds, and formation of fog as the nearly saturated air offshore is advected shoreward over colder coastal water. Phase four is entered as coastal indices approach their original value, and marine fog is advected over the coast as the prevailing northwesterly wind re-establishes the marine layer under the near-surface inversion. The fog development model is terminated as the base of the inversion is raised above about 400 meters and the stratus regime begins.

What initially appeared to be confirmation of an already existing fog development model (Leipper, 1948) took a new twist when the author re-evaluated the first two phases of the model for each sequence. It

was now noticed that the one-to-two day lag periods (of the coastal temperature and humidity index trends) on each side of the surface inversion formation coincided with a specific evaluation of net air flow (weak/strong, marine/continental) across the coast. The NOAA II satellite photographs confirmed that the relative length of the observed lag period and associated net air flow evaluation was significant in the location of the offshore stratus-fog cloud formation.

When the net air flow across the central California coast was evaluated as being a weak marine or weak continental flow (18-29 April and 6-19 May sequences in Appendixes C and D), coastal indices changed slowly, taking three-to-four days to reach their extreme values and fog-stratus clouds formed in a narrow band just off the coast. Strong continental flow of warm, dry air across the coast produced rapid coastal index changes and rapid surface inversion formation on the order of one-to-two days (25-31 May and 22-30 September sequences in Appendixes A and E). Satellite photographs for 28 May and 28 September showed a fog-stratus cloud formation at approximately 20-40 nautical miles off the coast with clear conditions in between.

The duration of coastal index trends through to their extreme values then, represents a transition period in which warm, dry air of continental origin displaces the normally-present marine layer from the coast to some distance offshore.

The next logical step was to define a transition zone or interface where the continental air mass converges with the marine layer. For discussion purposes, this transition zone phenomenon will be referred to as the Coastal Convergence Zone (CCZ). Several studies have alluded to the existence of the CCZ in the course of their fog development research.

In describing the displacement of the marine layer by dry warm air, Leipper (1968) speculated that strong downslope easterly winds drive the marine layer out to sea requiring that a new marine layer form under the dry warm air (to establish a surface invasion).

A study examining the coastal air-sea interactions and the extent of coastal influence (Environmental Prediction Research Facility, 1972; and Laevastu, 1973) mentions the existence of a coastal front 18-36 nautical miles offshore of Point Arena, just to the north of San Francisco, California. This particular study appears to have caught a fog development sequence progressing through phase two into phase three of the fog model (Leipper, 1948) under the influence of a strong continental air flow across the coast. This coastal front was well defined by significant changes of sea surface and surface air properties seaward from the coast. The coastal front boundary was characterized as having a sharp thermal inversion with a humid layer below it, accompanied by marked changes in the surface winds. Air temperature fluctuations in the form of cold and warm waves near the surface led to speculation of the existence of boundary waves of warm and cold air extending out from the coast.

Another study also speculated about a boundary wave, in the form of a possible gravity type wave generated out from the coast (Wright, 1975). Using a private aircraft, several flights were made off the coast near Monterey, California. A decrease in the height of the inversion seaward to approximately 25 nautical miles was found when weaker inversions existed at Oakland. When strong surface inversions were present, the height of the inversion remained constant to seaward.

Obviously, the strength of the surface inversion is important in determining the net air flow across the coast and influences the seaward extent of the proposed boundary wave.

A final study to be discussed here in establishing the background of the CCZ deals with the convergence of air masses as it relates to vertical motions in coastal fog (Pilie et al, 1976). This study also appears to have dealt with a phase two and early phase three fog developmental period but under a weak continental (warm and dry) air flow influence. The fog patch being investigated was located in a narrow band just offshore between Point Arena and Point Mendocino, California. This fog patch was subjected to northwesterly winds entering the western fog boundary while, nearer the coast, the winds had easterly components or were calm. The convergence pattern results in a net upward flow that deepened the fog layer.

The observations from these studies just discussed tend to closely coincide with those the author obtained from his data. The four main concepts postulated from the studies to explain their observations were: 1) the existence of boundary or gravity-type waves in the atmosphere; 2) the presence of a coastal frontal zone which separated the oceanic regime from coastal influence; 3) the strong downslope easterly winds that drive the marine layer out to sea; and 4) the convergence of marine and continental air masses near the coast. It was noticeable in reviewing these studies that only certain phases, normally phases two and three of the fog development model (Leipper, 1948), were observed. Therefore, only a partial picture of the existing atmospheric conditions was presented. The proposed Coastal Convergence Zone, which when defined and then described for each phase of the fog development model (Leipper, 1948), should present a complete illustration of the offshore fog development model.

The Coastal Convergence Zone (CCZ) will be defined as: an atmospheric transition zone of mesoscale dimensions situated over or near a coastal domain, bounded by relatively warm dry air landward and by an oceanic marine layer seaward; during the fog formation phase, the CCZ becomes a fog layer and is referred to as such. The location and width of the CCZ is directly dependent upon the direction and magnitude of the net air flow across the coast. Further amplification of the parameters associated with the CCZ were applied to a hypothetical marine fog development model. This model augments the original fog model (Leipper, 1948) in two ways.

The first is the addition of a phase zero which describes the initialized synoptic conditions. These conditions establish the marine layer over the coastal regions (denoted by the absence of a temperature inversion below 400 m) and account for the formation and dissipation of stratus conditions (without the occurrence of the other four phases of the fog development).

The second enhancement is an application of net air flow (strength and direction) evaluations, plus the location of lower atmosphere inversions and coastal index trends to estimate the location and width of the CCZ in phases one through four. The author observed that as the air flow evaluations changed from a strong onshore flow of cool moist air (caused by the prevailing northwesterly winds) to offshore flow of warm dry continental air, a corresponding decrease in the relative value of the upwelling index occurred. As the prevailing northwesterly winds returned, the upwelling index immediately increased. Since the upwelling index is only a calculation of potential upwelling, or water mass turn-over, based on pressure gradient and wind fields (direction and magnitude), and not on a physical measurement of the water mass properties, the author employed the upwelling

index trends as an indicator of the net air flow properties for the offshore study area.

D. HYPOTHETICAL MARINE FOG DEVELOPMENT (MFD) MODEL

The synoptic and mesoscale descriptions used in the discussion of a hypothetical five phase Marine Fog Development (MFD) Model are a combination of those for two locations that bracket the study area: to the south, Point Mugu (Rosenthal, 1972), and in the northern part of the study area, Alameda (Naval Weather Service, 1972). The discussion of the MFD Model primarily covers the summer fog period from April to October (Beardsley, 1976) or the "stratus season" (Rosenthal, 1972) when stratus and accompanying fog and haze are so prevalent along the central California coast. A summary of the primary and secondary features of each phase are presented in Appendix A.

The fundamental criterion for identifying each phase of the MFD Model will be the presence or absence of a temperature inversion in the lower 400 meters of the air column over the coastal and offshore study area. Phase identification can be further amplified by the synoptic and mesoscale variations in the atmospheric circulation patterns that govern the air column.

The initial phase of the MFD Model, phase zero, is the synoptic phase in which the subtropical Pacific High pressure cell dominates the atmospheric circulation over the Eastern Pacific Ocean. The Pacific High causes the prevailing northwesterly winds along the central California coast which results in an onshore flow of cool moist marine air over the coast. At higher levels, the Pacific High produces subsidence of warm dry air over the marine layer which normally causes a persistent formation of night and morning coastal low stratus with a ceiling at about the base of

the subsidence inversion. Phase zero, then, is defined by a radiosonde sounding which displays no thermal inversion below 400 m and the surface air temperature close to the sea surface temperature.

Phase one encompasses the formation of the Coastal Convergence Zone in the vicinity of the coast and nearshore zones. This phase is triggered as the Pacific High migrates toward the northeast or weakens offshore, allowing a thermal trough to extend northward into central and northern California. As a result, the prevailing winds offshore veer northward and weaken, while weak easterly winds bringing in warm dry continental air are introduced to the coastal zone. The continental air displaces the marine layer out to sea forming the CCZ over the coast and nearshore zones. These conditions of offshore flow tend to produce clear skies along the coast as the stratus is dissipated or displaced further offshore. The radiosonde sounding for phase one would display no thermal inversion below 400 m, similar to phase zero; however, the surface air temperature would be greater than the sea surface temperature.

Phase two is the air mass saturation or pre-fog phase. The thermal trough over California becomes the dominant synoptic feature controlling the atmospheric circulation over the central California coast and moves westward over the coastal and offshore areas. This causes a strengthening of easterly winds over the coast which increases the warm dry continental air flow into the coastal areas and over the nearshore zone. The location of the seaward edge of the CCZ is dependent upon the strength of the continental air flow off the coast. The moisture content of the warm dry air within the CCZ and seaward of the coast increases to near saturation. A radiosonde sounding during phase two would display a surface inversion with the air temperature greater than the sea surface temperature.

Phase three is the fog phase which occurs as the Pacific High resumes dominance of the atmospheric circulation over the Eastern Pacific Ocean and the thermal trough is displaced eastward over the interior of central California. Weak prevailing northwesterly winds return to the nearshore zone advecting the CCZ (with its lower layer near saturation) shoreward over the cooler coastal waters. Fog is formed by cooling from below and the CCZ becomes defined by the extent of the fog layer. Radiational cooling from the white cloud tops (of the fog layer) cools the fog layer further while convergence of marine and continental air masses produce vertical motion and mixing within the fog layer, which increases the fog layer depth. During phase three, the thermal inversion based at the surface deepens and the surface air temperature falls below the sea surface temperature.

Phase four is the terminal or stratus phase. During this phase, the Pacific High again dominates the atmospheric circulation over the Eastern Pacific Ocean. Strong prevailing northwesterly winds are returned to the nearshore and coastal zones which advects the marine layer shoreward and displaces the CCZ and continental air mass inland. As the moist marine air flows onshore beneath the lifting thermal inversion, fog is no longer formed at the surface and the fog layer lifts until a low stratus overcast covers the coastal and nearshore zones. During phase four, the thermal inversion lifts from the surface to some height above 400 m where fog ceases to form and stratus remains. The surface air temperature approaches the sea surface temperature.

E. PROBLEMS ENCOUNTERED

This study, similar to the study by Schrock (1976), used transient ship weather observations as a data base where neither fixed point nor

time series analyses could be used. In order for a study of this type to be thorough and yield definitive results, it would have been desirable to have had accurate and high density data available. The data used in this study met neither of the criteria which was a large disappointment to the author.

Needless to say, the quality and quantity of the data placed stringent limits on the scope and usefulness of this study.

The facts associated with the quantity criterion are noteworthy. For the year 1973, there were 954 transient ship reports (includes all sources and reporting times) in the study area. This averages out to 2.6 reports per day within the approximately 25,800 square nautical miles of the study area. The second statistic of interest is that there were 78 synoptic days where there were no reports and 80 synoptic days represented by 1 report. This means that 43 percent of the days in 1973 cannot be described in any detail. The maximum number of reports for any one day was 20.

The location of the reports within the study area was also significant. Although only 31 percent (299 of 954) of the reports were actually plotted on the work charts, the author estimates that less than half of the reports could be used directly to support the data from the coastal stations; the remainder of the reports lie in the adjacent portions to the north and south within the study area. The data, at best, are sparse and when subjected to the quality criteria, the data base becomes very unsophisticated.

Liaison with the National Climatic Center (NCC) and Naval Weather Service Detachment, Asheville, North Carolina (Lepore, 1976), regarding the validity of the temperatures received, especially the sea surface

temperature which was considered to be a critical parameter for a marine fog study, yielded additional disconcerting information. Surface marine data acquisition by NCC shifted from the multiple-source (ship weather reporting forms, ship logs, and exchange/purchase of foreign data) mode to a single source in mid-year 1973. The monthly data tapes compiled at the Air Force Global Weather Central (AFGWC) were made available to NCC approximately 60 days after the close of each data month. The data from AFGWC were then converted to TDF-11 format utilized by NCC. During the initial conversion processing in late calendar year 1973, several inconsistencies, specifically in the coding of sea surface, dewpoint and wet bulb temperatures, were discovered in the AFGWC data. These problems were not rectified until mid-year 1974; meanwhile, the 1973 file from AFGWC remains as initially received and converted by NCC.

In an effort to salvage the data obtained from NCC, coincident data for the four fog development sequences were requested and received from the Climatology Section, Fleet Numerical Weather Central (FNWC), Monterey, California. The printout from FNWC included an additional 83 reports (to the 216 reports from NCC) but did not have 23 reports supplied by NCC. These differences were attributed to the shift in data acquisition modes and data availability logs from NCC and to problems encountered by FNWC in the changing of their storage programs resulting in a few tapes of 1973 data being destroyed. The data from FNWC also had its limitations in that the air temperature and dewpoint temperature were truncated in whole degrees Centigrade, the dewpoint temperature was often not reported (which coincided with the NCC data), and the wet bulb temperature was not printed. A minor supplemental source of base data were the reports plotted on the NMC final analysis charts. These reports filled some gaps

left by both NCC and FNWC. But again, they were of limited value since the temperatures were in whole degrees Fahrenheit, which when converted to degrees Centigrade were accurate to only six-tenths of a degree Centigrade.

Schrock (1976) discusses additional factors that affect the quality and limitation of transient ship observations as a base. These include the inherent difficulties of making observations at sea, the attitude and training of the observers, transmission and coding errors, and the lack of upper air soundings.

In summary, the transient ship reports used in this study are sparse in location and highly suspect as to their usefulness. However, one has no other alternative but to use the ship reports to verify the existence of marine fog conditions. The extent and detailed character of small scale local features will be difficult to determine. Results and conclusions must be approached cautiously in order to maintain any acceptability.

F. CREDIBILITY OF "FOGGER" DATA

The determination of the presence of fog can be made from three elements of the surface marine observation report. They are visibility, present weather and past weather. The fog-related codes and the imposed limits of the visibility-weather groups were discussed and tabulated by Schrock (1976), who then identified five types of inconsistencies observed in his data and which were evident in the data used in this study.

The first three inconsistencies involve codes to report fog conditions at the station and at the time of observation. Types A and B inconsistencies involved the present weather codes of 40-49 (heavy fog) and 11-12 (patches or continuous shallow heavy fog), having a higher visibility

than the defined limit of less than one kilometer (90-93). Similarly, type C inconsistency was the present weather code 10 (deep light fog) having a visibility code greater than the allowed limit (93-96). Type D inconsistency was described as too low a visibility (90-94) reported with the present weather code of 28 (fog at the stations during the preceding hour but not at the time of observation). The last inconsistency, type E, was the occurrence of a reported visibility of less than 1000 meters without an appropriate present weather code (40-49, 11-12).

A computer printout of the "foggers" was filtered out of the 37991 surface marine reports received from NCC for the EASTPAC Study Area and was manually screened for the five types of inconsistencies. This analysis was then compared to the results from Schrock (1976) which are compiled in Table I and shows a fair degree of correlation when one considers the data base. Both studies analyzed basically the same oceanic area off the North American coast but for different periods. Schrock obtained a higher percentage of "foggers" (25 percent) in his data base since his study covered two known fog sequences while this study covered a full year with "foggers" representing only 10 percent of the data base. The comparison of the actual percentage of inconsistencies between the two studies is not an important feature, but it is important that both studies had a relatively high percentage of inconsistencies. When a quarter to nearly half of the surface marine observations reporting fog do not meet the standard definitions promulgated by the WMO, it is quite evident that observers at sea are unfamiliar with or uninterested in their observing duties.

The SSR-75 program (Willms, 1975) appears to give the best indication of the presence and duration of fog since the scheme uses all three elements of the visibility-weather group. Although the inconsistencies still

Table I. Visibility-Weather Group Coding Inconsistencies (Schrock, 1976)

A. Too high a visibility reported with a present weather code of 40-49 (heavy fog)

B. Too high a visibility reported with a present weather code of 11-12 (shallow heavy fog)

C. Too high a visibility reported with a present weather code of 10 (deep light fog)

D. Too low a visibility reported with a present weather code of 28 (fog within one hour of observation, but not at time of observation)

E. No fog-related present weather code with a reported visibility of less than 1000 m

Type Inconsistency	Present Weather Code	EASTPAC "FOGGERS" # of times reported	# of inconsistencies	%	SCHROCK (1976) # of times reported	# of inconsistencies	%
A	40-49	758	404	53	194	106	55
B	11-12	152	129	85	17	16	94
C	10	548	230	42	69	16	23
D	28	111	20	18	20	3	15
E	-	-	110	-	-	2	-
Total			893			143	

EVERMANN - Calendar year 1973	SCHROCK - Two known fog sequences
3838 Foggers/37991 Reports = 10%	360 Foggers/1427 Reports = 25%
893 Inconsistencies/3838 Foggers = 23%	143 Inconsistencies/360 Foggers = 40%

exist, the SSR-75 program is designed to handle the various combinations of the visibility-weather group codes in assigning duration values.

Another aspect of the credibility of the data base used in this study was that of a day-night bias in reporting fog. Table II shows a tabulation of surface marine observations and "foggers" compiled by month and synoptic reporting time. The results ruled out the possibility of a local day-night reporting bias regarding the occurrence of fog reports. Of the 954 observations used in the main portion of this study, 577 (60.5 percent) occurred in the day time hours while 377 (39.5 percent) were reported at night. There were 138 "foggers" (14.5 percent) reported of which 84 were in the day and 54 at night corresponding to 14.6 and 14.4 percent respectively.

The difference in the number of day and night observations could be attributed to the fact that most transiting ships schedule their arrival and departures to coincide with daylight hours; and if at sea, some units take weather observations only during the daylight hours to cut the costs and manning levels of night time operations.

The fair weather bias, which is the tendency of ships to avoid bad weather resulting in their observations reflecting mostly good weather, was also not considered to be a credibility detracting factor (Edgerton, 1974), especially for a coastal study since transiting ships have little leeway for skirting bad weather while in coastal waters.

Table II. Tabulation of Ship Observations and "Foggers" by Month and Synoptic Reporting Time

Month	Night Observations 0600 GMT 2200 PST	Night Observations 1200 GMT 0400 PST	Day Observations 1800 GMT 1000 PST	Day Observations 0000 GMT 1600 PST	Total by Month Obs/Foggers
Jan	9/0	10/0	13/1	20/1	52/2
Feb	10/1	2/0	25/2	12/0	49/3
Mar	4/0	5/0	17/1	14/0	40/1
Apr	50/5	60/1	68/6	64/3	242/15
May	40/7	43/9	51/11	33/3	167/30
Jun	8/1	7/0	5/0	13/2	33/3
Jul	12/3	10/3	21/4	14/2	57/12
Aug	11/3	12/2	31/8	21/3	75/16
Sep	15/5	10/2	26/10	15/4	66/21
Oct	8/0	6/1	20/5	10/0	44/6
Nov	13/1	9/1	25/6	10/0	57/8
Dec	14/5	9/4	26/7	23/5	72/21
Total	194/31	183/23	328/61	249/23	954/138
	Night Observations 377/54		Day Observations 577/84		
	39.5% of Observations		60.5% of Observations		
	14.4% Foggers		14.6% Foggers		14.5% Foggers

III. ANALYSIS RESULTS

A. CY 1973 OFFSHORE/COASTAL FOG OBSERVATION ANALYSIS

In this portion of the study, the number of ship observations and those reporting fog were recorded for each of the synoptic reporting times for each day during 1973. The hourly visibility data for each of the coastal stations (Beardsley, 1976) was then graphed. A final bit of information added prior to analysis was the approximate time of each frontal passage over or near the study area (American Meteorological Society, 1973 and 1974).

During the analysis, it was hoped that trends or patterns of fog occurrence would be observed. However, no readily apparent trends were observed with the possible exception that when fog was observed offshore, it normally coincided with restricted visibility (heavy, and light fog or haze) or low overcast reported over the coast.

The scarcity of offshore data and the lack of a detailed synoptic description were the two main factors responsible for the inconclusive results.

A more detailed comparison of these offshore and coastal observations might, at least, steer an investigator toward some interesting feature or sequence for further research.

A copy of the rough analysis for this portion of the study is on file with the Chairman, Oceanography Department, Naval Postgraduate School, Monterey, California 93940.

B. GENERAL COMMENTS

The following remarks are included in order to standardize the terminology, definitions and abbreviations to be used in discussing the marine fog sequences and subsequent model and analysis summaries (found in Appendixes A through E).

1. All references to time are Pacific Standard Time (PST, +8U), the local time for California and adjacent offshore areas.

2. NOAA II satellite photographs will be referred to as "NOAA-2 imagery (time)" with the local time of the overhead pass in parenthesis. Similarly, "ship observations (time, location)" with the local time and relative location, as necessary, inside the parenthesis.

3. All references to height will have units in meters (m), visibilities and distances will be in nautical miles (nm), cloud cover will be in units of tenths, and temperatures will be in degrees centigrade (°C).

4. References to inversions or Oakland soundings imply the 0400 radiosonde sounding taken daily at Oakland International Airport (Beardsley, 1976).

5. Coastal data (Beardsley, 1976) include the following:

   a. Base of Inversion (BI) - height of the inversion base, listed as one of the non-diurnal indices which characterize fog formation, and provides the primary criterion for phase determination in the MFD Model.

   b. Coastal (temperature and moisture) indices -

      (1) Moisture Index (MI) - the 1600 surface dewpoint at Oakland minus the sea-surface temperature, high positive values indicate a high degree of saturation in the surface air.

(2) Temperature Index (TI) - the 0400 temperature at the top of the inversion minus the sea surface temperature, a relative measure of the inversion gradient and of overall atmospheric stability of the air column.

(3) Hidden Hills maximum daily temperature (HHT_M) and minimum daily relative humidity ($HHRH_m$) - daily temperature and relative humidity values from a location about 10 miles inland from Monterey Bay, at a height of 262 m.

c. Upwelling Index (UI) - calculated using six-hourly synoptic surface atmospheric pressure fields, high values are indicative of northwesterly winds over the Study Area.

6. From the coastal indices, warming or cooling trends could be detected. A warming trend indicative of the flow of warm dry air into the coastal area would cause the moisture index, temperature index and Hidden Hills maximum temperature to increase and the Hidden Hills relative humidity would decrease. Similarly, a cooling trend connoted the flow of cool moist air into the coastal area and would be detected by a reversal of index values.

7. Throughout the sequence discussion which follows next in this section, the terms warm dry air and continental air are synonymous and likewise, for cool moist air and marine air (or marine layer).

8. The study area will be divided, for discussion purposes, into four basic meridional zones and three latitudinal sub-study areas. The four meridional zones are:

a. Inland Zone (Inl) - from the foothills of the coastal mountain ranges eastward.

b. Coastal Zone (Co) - region that extends from the sea inland to the foothills of the coastal mountain ranges.

c. Nearshore Zone (Nsh) - variable width region which extends seaward from the shoreline and is evaluated to be under coastal influence.

d. Offshore Zone (Ofs) - remainder of the study area seaward of the nearshore zone.

The three latitudinal sub-study areas are:

a. Northern Study Area (NSA) - the study area north of 38° north latitude.

b. Middle Study Area (MSA) - located between 36° to 38° north latitude.

c. Southern Study Area (SSA) - located south of 36° north latitude.

9. The conditions associated with each phase of the MFD Model, as summarized in Appendix A, were applied separately to both offshore and coastal portions of the study area. The location of the inversion base was the primary criterion for coastal fog phase identification while marine fog phases relied heavily on evaluated offshore conditions associated with inversion height fluctuations.

C. MARINE FOG SEQUENCE ANALYSES

Four actual marine fog sequences will now be examined using the proposed Marine Fog Development Model (MFD Model) discussed earlier and the Data Analysis Summaries located in Appendixes B through E. The sequences will include an additional day added to the beginning of each sequence studied by Beardsley (1976) to determine if phase zero conditions existed.

1. <u>25-31 May 1973</u>

The first fog sequence, 25-31 May 1973, represents an uninterrupted case of fog development. This sequence very closely parallels the ideal marine fog development with a strong continental (offshore) air flow

as discussed in the MFD Model. This sequence is fully documented in Appendix B as a sample of how the remainder of the analyses were conducted.

On 25 May, phase zero conditions were evaluated for the study area based on the persistent synoptic conditions offshore. Relatively high values for the upwelling index (derived from northwesterly winds) and coastal index values indicative of cool moist air connoted the presence of a marine layer over the coastal regions which had existed for the preceding three days. The passage of a cold front late in the previous day left the study area clear of clouds as observed from the NOAA-2 imagery (1040). On 26 May, five ship observations verified that the prevailing northwesterly winds had veered northward and weakened offshore. This was caused by the eastward movement of the Pacific High and ridge of high pressure that pushed inland, overlapping the Pacific coast. Phase two conditions for the study area initiated at mid-day were signified by the veering and weakening of winds offshore and a slight warming trend observed at the coastal stations later in the day. A lone ship report (2200, 30 nm west of Pigeon Point) of weak north-northwesterly winds and a relatively high night-time air temperature (14°C) tends to support the offshore flow of warm air from the coast. The CCZ was evaluated as covering the coast and nearshore zone, pushing seaward and strengthening over the coastal areas as the warm dry continental air became established over the coast. On 27 May, a shallow surface inversion was recorded at Oakland along with a warming of the entire air column. The NOAA-2 imagery (1035) showed a thin and scattered stratus cloud development 20-30 nm seaward from the coast concurring with two early morning ship reports of three-tenths low cloud coverage approximately 30 nm

offshore. Phase two conditions continued to exist over the study area during 28 May. The surface inversion recorded at Oakland showed an intense strengthening while the coastal indices approached or reached their extreme (warming trend) values. A relatively strong seaward flow of continental air was estimated based on the location of thermal trough overlapping the California coast, rapid warming of the coastal area and the presence of a clear air band 40-50 nm wide paralleling the coast. NOAA-2 imagery (0935) showed a well-defined fog-stratus cloud formation seaward of the clear air band. Two ship observations from the far western edge of the study area verify the near-total low overcast conditions while reporting northwesterly winds of 15-20 knots and relatively high air temperatures. Another ship observation 120 nm north of the study area (taken from the NMC Final Analysis chart coinciding with the time of the satellite photograph) and located in the shoreward edge of the fog-stratus cloud which extended northward along northern California, reported fog and total overcast condition. It is speculated, based on these ship observations, that the shoreward edge of the fog-stratus cloud is a surface -based fog and further seaward lifts to become stratus. If this is so, then the fog-stratus cloud formation defines the location of the CCZ. The evaluated offshore air flow from the coast and the northwesterly winds reported by the western area ships tend to support possible air mass convergence in the vicinity of the fog-stratus cloud formation.

Phase three conditions occurred offshore early in the morning of 29 May as the strengthening Pacific High brought the return of weak northwesterly winds along the California coast (based on ship reports adjacent to the study area and the increased value of the upwelling index). The NOAA-2 imagery (1030) showed that the fog-stratus cloud had been advected shoreward and, based on reported low visibilities at the

coastal stations, moved inland as fog by early afternoon. The CCZ, now defined by the extent of the fog layer, covered the nearshore zone and coastal area. Phase three conditions over the coast were observed early on 30 May with the lifting of the base of the inversion to 150 m recorded at Oakland. Fog was reported by one of two ship observations taken in the early morning hours off Pillar Point. The other ship observation located in the northern study area reported 20 knot northwesterly winds and almost total low cloud overcast. All the coastal stations reported fog most of the day through to mid-morning on 31 May. The Oakland sounding on 31 May recorded the base of the inversion at 750 m signifying phase four conditions. By mid-morning, all the coastal stations and one ship observation (1000, 20 nm southwest of Point Pinos) reported only overcast conditions.

2. 18-29 April 1973

The second sequence examined was 18-29 April 1973. This sequence also followed the MFD Model but included a slight interruption caused by passage of a cold front over the central California coast mid-sequence.

On 18 April, phase zero conditions were diagnosed for the study area based on the consistent values of the coastal indices and high upwelling index values associated with the persistence of the Pacific High offshore for several preceding days (16-18 April). Some scattered overcast reported offshore late in the day (by ships bordering the study area) was associated with the rapid passage of a weak cold front across the central California coast late in the evening. By mid-morning on 19 April, numerous ship reports confirmed that the study area was mostly clear of overcast and strong northwesterly winds of 15-30 knots were prevalent over offshore area. Phase one conditions over the coastal area were evaluated based on a slight warming trend observed in the coastal

indices but phase zero was still in effect offshore due to the strong northwesterly winds. By 20 April, the surface inversion was recorded at Oakland (phase two over the coast) accompanied by definite warming trends in the coastal indices. The offshore winds weaken slightly as observed from seven ship reports in the northern study area and the upwelling index decreased. Weak phase one conditions were evaluated offshore based on these observations. On 21 April, ship observations reported a further reduction of winds throughout the day so that by mid-afternoon, winds were weak and predominantly north-northwesterly about 40 nm offshore (phase two). The estimated location of the CCZ over the clear coastal and nearshore zones out to about 40 nm was based on the strength of the coastal warming trends and weakening winds offshore. On 22 April, the NOAA-2 imagery (1102) showed the presence of a cloud mass very near the surface (denoted by a very light grey shading contrasted against the darker land mass and deeper grey oceanic region further offshore) which was supported by three ship observations (1000, 40 nm west of Pillar Point). Two of the ship reports plotted just seaward of the cloud mass reported clear conditions and calm or weak winds. The third observation, also reporting calm conditions, was located near the offshore edge of the cloud mass, and reported a deep light fog (with a horizontal visibility of greater than 6 nm, a type C inconsistency listed in Table III). Later in the day overcast conditions prevailed over the study area as a cold front passed through the study area mid-evening. This disturbance was significant in that coastal indices that appeared to be very close to their extreme values (indicating the start of phase three and subsequent fog formation) were reversed rapidly to previous phase two index values near those for 20-21 April. Early phase two conditions were also observed offshore on 23 April as numerous ship reports reflected the return of 15-25 knot

northwesterly winds in the northern and middle study areas. NOAA-2 imagery (1002) showed a low cloud formation about 10 nm offshore from Monterey Bay southward over the study area. The low cloud formation in the southern study area is thought to be an advanced phase two CCZ remnant from the previous day which was advected southward by the frontal passage and northwesterly winds.

On 24 April, NOAA-2 imagery (1057) showed that the fog-stratus cloud wedge had moved north along the entire coast of the study area. Eight ship observations in the middle study area verified the seaward limits of the fog-stratus cloud offshore and reported northwesterly winds of 15-25 knots. A ninth ship observation which plotted mid-way through the fog-stratus cloud reported very weak northwesterly winds. Two additional ship observations in the southern study area within 20 nm of the coast reported weak winds with a southerly component and also verified complete overcast conditions. Based on three "foggers" and their assigned duration, fog was present offshore shortly before noon which coincided with the occurrence of fog at all the coastal stations. The coastal indices reflected the return of warm dry continental air and the surface inversion at Oakland strengthened as recovery from the frontal passage was completed. The CCZ, now the fog layer, remained stationary over the coast and extended seaward approximately 30 nm. On 25 April, phase three conditions were evaluated offshore. The fog layer appears to have been advected towards the southeast based on NOAA-2 imagery (0957) by strengthening northwesterly winds north of the study area. Eight ship observations in the middle study area near the fog-stratus cloud wedge all reported varying amounts of overcast, weak northwesterly winds but no fog. Phase two continued over the coast as the coastal indices reached their warming trend extreme values and all the coastal

stations reported fog or overcast during the day. Phase three conditions over the study area were accelerated on 26 April by the rapid approach of a frontal system. By late afternoon, and probably coinciding with the frontal passage over the coast, the base of the inversion lifted from the surface. A cooling trend was observed from the coastal indices and predominately heavy fog was reported at all coastal stations. Fifteen ship observations in the middle study area reported weak winds primarily out of the west. Two offshore observations of fog, as well as the offshore wind, were attributed to frontal activity. On 27 April, 17 ships observations indicated the return of the prevailing northwesterly winds to the offshore area. Consistent with the NOAA-2 imagery (0952), most of the ship observations reported near-total low overcast conditions offshore (phase four). The Oakland sounding recorded the base of the inversion at 470 m (phase four over the coast), and the coastal indices continued their cooling trend. Fog was present at the coastal stations lifting to low overcast by mid-afternoon. By 28 April, the marine layer was well established over the coastal area by the prevailing onshore flow and continued through 29 April. Phase zero conditions were evaluated for the study area on 29 April because the air circulation over the study area was dominated by the Eastern Pacific High.

3. <u>5-19 May 1973</u>

The third sequence examined was from 5-19 May 1973. The rapid movement of several successive frontal systems over the study area prevented the continuous development of marine fog formation as described in the MFD Model. This sequence represents the typical summer fog development case for the California coast (Beardsley, 1976).

Following the passage of a cold front late on 3 May, which accelerated fog development to phase four conditions over the study area,

the Pacific High established the air circulation pattern over the eastern Pacific Ocean. By 5 May, a ridge of high pressure that overlapped the northern Pacific coast returned a weak warm air flow of continental air to the central California coast. Phase three conditions were observed over the coastal study area signified by a weak surface inversion at Oakland. Offshore winds in the study area were estimated to be north-northwesterly at 20 knots based on ship reports adjacent to the study area. Coastal winds in the vicinity of Monterey Bay were reported as westerly at 20 knots (taken from the NMC final analysis chart). Based on these offshore winds and the near-total overcast conditions (of cumulus and stratocumulus) reported adjacent to the study area and over the coast, phase four conditions were evaluated for the offshore study area. On 6 May, NOAA-2 imagery (1028) indicated a complete cloud cover over the southern half of the study area and clear in the northern study area (verified by five ship observations). An approaching frontal system cloud band was located at the northwest corner of the study area. Ship observations in the northern study area reported strong northwesterly winds and the Oakland sounding recorded the base of the inversion at 700 m indicating phase four conditions over the study area. The passage of the cold front early in the morning of 7 May left the study area mostly clear of overcast. An isolated offshore fog observation and early morning overcast reported by the coastal stations were attributed to frontal activity. The clear skies, slight warming trend (inferred from 8 May coastal data) and weakening northwesterly winds offshore indicated a weak phase one. By 8 May, a shallow surface inversion was recorded at Oakland and the coastal indices reflected the presence of warm air (phase two). Ship observations within 60 nm of the coast reported weak (3-10 knot) northwesterly winds while a lone ship observation (70 nm southwest of Point Pinos) reported

stronger (30 knot) northwesterly winds further offshore. NOAA-2 imagery (1023) showed a thin-textured fog-stratus cloud formation about 30 nm offshore and paralleling the coast. An afternoon offshore report of fog in the northern study area indicated that the fog-stratus cloud was being advected shoreward (phases two and three). Also evident from the satellite photograph was the approach of another frontal system from the northern Pacific. By late evening, seven of nine ship observations from the northern study area reported fog which the author attributed to frontal activity. By mid-morning on 9 May, ship observations in the northern study area reported scattered overcast conditions that concurred with the NOAA-2 imagery (0924) which showed scattered fog-stratus clouds over the study area. The return of strengthening winds (20-25 knots) in the afternoon that was reported by the ships in the northern study area (phase three) was a result of the Pacific High establishing a strong air circulation pattern over the eastern Pacific. On 10 May, phase two conditions were restored to the study area. As the Pacific High migrated to the north-northeast and a thermal trough protruded into southern California, a strong flow of continental(warm and dry) air into the coastal area was established. The Oakland sounding recorded a weak surface inversion with a stronger inversion gradient at 210 m and the coastal indices reflected the presence of warm, dry air. NOAA-2 imagery (1019) showed the study area to be clear. Observations from 11 ships, located within 40 nm of the coast and evenly distributed along the entire coast, tend to support possible convergence and horizontal mixing of marine and continental air masses offshore. Ship observations from the northern study area reported 20-30 knot northwesterly winds and an air temperature of abour 11.5°C. A lone ship observation 30 nm west of Pillar Point reported 10 knot easterly winds with a 16.7°C air temperature. The

ship observations from Point Pinos southward reported 10-25 knot northwesterly winds with air temperatures of 13° and 14°C, almost 2°C higher than those from the northern study area. Based on these observations, the CCZ (seaward boundary) extended southward from Point Reyes and inland over the coastal area. The observations from 10 May proved to be significant because on 11 May, NOAA-2 imagery (0918) showed a fog-stratus cloud wedge along the coast from Point Pinos southward. Two of three ship observations in the southern study area and Point Pinos reported fog (while Monterey Airport reported overcast) mid-day. By 12 May, the fog-stratus wedge had moved northward along the entire study area, from the coast seaward to 124° west longitude. Three ship observations about 40 nm from the coast reported calm or weak westerly winds, and near-total overcast (with one report of fog). The coastal stations reported fog most of the day, otherwise overcast. The location of the CCZ is now defined by the fog layer. The Oakland sounding recorded the base of the inversion at 250 m and the coastal indices reflected a slight cooling trend (phase three). Fèw changes were observed on 13 May as the coastal indices continued their cooling trend and fog or overcast prevailed over the coastal area. Ship observations reflected the return of weak northwesterly windsoffshore (phase four). NOAA-2 imagery (1009) for 14 May indicated an inland movement of the fog-stratus cloud and thinning (or dissipation) along the seaward edge. Two ship observations within 40 nm of the coast reported partial low cloud overcast and the coastal stations reported fog lifting to haze and overcast during the day indicative of phase four over the study area. On 15 May, the approach of a cold front from the northern Pacific appeared to disturb the offshore air circulation along the California coast causing stagnant atmospheric conditions over the coast. No notable changes from the previous two days were

observed. By 16 May, the cold front offshore weakened and dissipated before reaching the study area but was followed closely by another frontal system. The Pacific High recovered from the previous day to establish moderate strength (10-20 knot) northwesterly winds over the study area. NOAA-2 imagery (1004) shows a uniform fog-stratus cloud band 40-50 nm wide paralleling the entire central California coast. Four ship observations in the northern study area report fog conditions 20-30 nm offshore. A lone ship report further south (30 nm west of Pigeon Point) reported complete overcast conditions. Oakland recorded a weak surface inversion despite the slight cooling trend of the coastal indices. Light fog was reported by all the coastal stations. Based on the recorded surface inversion and the presence of fog both onshore and offshore, phase three conditions were evaluated for the study area. On 17 May, the Pacific High weakened as the frontal system offshore moved slowly eastward over the northeastern Pacific Ocean. NOAA-2 imagery (1059) showed the entire study area covered by a fog-stratus cloud band 100-120 nm wide. Four ship observations reported moderate northwesterly wind and fog in the northern, southern and western (120 nm west of Pigeon Point) portions of the study area. Heavy fog was reported by all the coastal stations most of the day. Late in the day the frontal system over the northeastern Pacific moved inland over the Pacific Northwestern States as another frontal system, the fourth in this sequence, moved southward from the northern Pacific Ocean. On 18 May, a ridge of high pressures separated the approaching frontal system from the coast and the conditions in the study area remained the same as the previous day. Two of the ship observations report fog while two others report near-total low cloud overcast. Fog and overcast was present at all the coastal stations. By 19 May, the Oakland sounding

recorded the base of the inversion at 500 m, coastal stations reported overcast conditions and a lone ship observation in the northern study area reported 20 knot northwesterly winds and partial low cloud overcast (phase four). NOAA-2 imagery (0900) showed a fog-stratus cloud overcast over the southern two thirds of the study area. The frontal system continued eastward over northern and central California late in the day.

4. 22-30 September 1973

The fourth fog development sequence analyzed was 22-30 September 1973. This sequence also follows the ideal fog development pattern as discussed in the MFD Model. Offshore fog development was slower in this case due to the presence of a persistent marine layer.

The passage of a frontal system in mid-afternoon on 22 September left the eastern Pacific under the influence of the Pacific High circulation pattern (phase zero). On 23 September, a slight warming of the air column at Oakland was recorded (phase one) while offshore, the prevailing northwesterly winds from the Pacific High were dominant (phase zero). NOAA-2 imagery (0938) showed the study area mostly clear with some scattered low overcast. Also evident was the approach of another frontal system from the northeastern Pacific Ocean. By mid-day on 24 September, the weakened frontal system passed over the study area. The cold front associated cloud formation was the primary feature on the NOAA-2 imagery (1035) supported by three ship observations that reported three-to-nine tenths low cloud coverage and weak westerly winds. On 25 September, the Pacific High dominated the air circulation over the eastern Pacific. A ridge extended to the northeast over the Pacific Northwestern States and a thermal trough stretched through the interior of California. The location of the ridge and trough features established a flow of continental air into the coastal regions of California which was reflected by the

surface inversion observed at Oakland and warming trend denoted from the coastal indices (phase two). NOAA-2 imagery (0934) showed the study area clear of overcast, a condition associated with the flow of warm air offshore from the coast (NavWeaSvc, NAS Alameda, 1972). However, based on two ship observations (1600 and 2200, 15 nm west of Point Pinos) that reported a 20 knot northwesterly wind and air temperatures (15.6°C) consistent with the previous day, a shallow marine layer was assumed to exist offshore (phase one). On 26 September, the thermal trough had moved just offshore and controlled the air circulation over the California coast. An early morning ship observation (0400, 60 nm south-southeast of Point Pinos) in the southern study area reported 10 knot south-southeasterly winds, indicating a wind reversal along the coast consistent with the observed isobar alignment. Another ship observation later in the day (2200, 15 nm southwest of Point Pinos) reported calm conditions and a higher air temperature (18.0°C) than those reported the previous day. Phase two conditions and the location of the CCZ were present over both the nearshore and coastal areas as the coastal indices continued their warming trend. The upwelling index verified the offshore calm conditions with a value of zero. On 27 September, the thermal trough weakened slightly and moved eastward directly over the northern and central California coast. NOAA-2 imagery (0930) continued to show the study area clear and coastal warming trends continued. Two ship observations and one coastal report tend to suggest possible convergence and horizontal mixing similar to the conditions discussed in the previous sequence. A ship observation (1000, 50 nm northwest of Pillar Point) in the northern area reported 5 knot northwesterly wind and an air temperature of 16.0°C. The coastal observation just south of Pigeon Point (and the same time of day) reported 5 knot northeasterly wind with an air temperature of 21.7°C. A third observation

(1600, 50 nm south of Point Pinos) later in the day from the southern study area reported no wind and an air temperature of 20.0°C. Again, these observations proved to be significant because on 28 May, NOAA-2 imagery (1022) showed a fog-stratus cloud band seaward of a clear area 15-25 nm offshore of the coast. The fog-stratus cloud band paralleled the coast from central California northward to the Washington coast. Although no ship observations in the study area were available, one ship observation just off the central Oregon coast, and located in the fog-stratus cloud band, did report total overcast and fog with 5 knot northerly winds. It is speculated that the landward edge of the fog-stratus cloud in the study area was fog. By mid-afternoon, all the coastal stations reported light and heavy fog. The coastal indices indicated that the warming conditions were at their maximum value while the upwelling index recorded a slight increase indicating the return of weak northerly winds (phase three). Coastal stations continued to report fog through most of 29 September, lifting to haze and overcast late in the day along the three southern-most locations. The NOAA-2 imagery (0923) showed the fog-stratus covering the entire study area to some indeterminate location inland. Two ship observations in the northern study area reported fog and 10-15 knot northerly winds while a ship observation further south (70 nm west southwest of Point Pinos) reported complete overcast conditions and 10 knot north-northwesterly wind. The rapid movement of a frontal system through the study area the morning of 30 September appeared to have accelerated the fog development to phase four. The base of the inversion at Oakland was recorded at 400 m and coastal stations reported overcast skies through most of the day. Four ship observations in the southern half of the study area reported near-overcast skies and predominant 10-15 knot northwesterly winds.

D. ANALYSIS SUMMARY

The first sequence, 25-31 May, represented an uninterrupted case of fog development which very closely paralleled the MFD Model. During the early portion of this sequence, a strong flow of warm dry continental air over the coast pushed the CCZ offshore rapidly so that by 27 May, weak fog-stratus cloud development was observed 20-30 nm offshore. On 28 May, when the continental air flow was at its maximum peak over the coastal area, the CCZ was located 40-50 nm offshore by a well-defined fog stratus cloud formation seaward of a clear air band that paralleled the coast. The return of northwesterly winds to the offshore region advected the fog-stratus cloud shoreward on 29 May and inland on 30 May. By 31 May, most of the fog reported over the coastal area had lifted to stratus.

The second sequence, 18-29 April, also followed the MFD Model but demonstrated the delaying effect of frontal passage on phase development. In the early portion of this sequence, the offshore phase development lagged the coastal development by about a day due to a persistent marine layer. By 22 April, both the offshore and coastal study area were in phase two with early development of fog-stratus clouds observed on NOAA-2 imagery. The frontal passage late in the day caused a reversal in the trends of the coastal indices and on 23 April, the upwelling index reflected the return of northwesterly winds behind the front. By 24 April, weak continental air flow returned to the coastal area, as fog formed along the coast. Both the continental air flow offshore and the marine air flow onshore were weak as fog occurred over the coastal and nearshore zones through 26 April. On 27 April, the northwesterly winds returned to the offshore zone, the marine layer moved inland under the fog layer, and stratus overcast prevailed on 28 April.

The third sequence, 6-19 May, was the typical summer fog development case for the California coast. Passage of four frontal systems during this sequence caused interruptions and reversals of fog phase development. It was difficult to determine the location of the CCZ and approximate timing of fog phase changes with the rapid changing of atmospheric conditions associated with each frontal passage. Phase development in the early portion of this sequence was irregular as the first two fronts passed over the study area on 7 and 8 May. By 10 May, weak continental air flow had returned to the coastal area but the prevailing northwesterly winds were strong. Possible air mass convergence was observed south of Point Reyes which by 11 May, appeared to be a formation area of fog-stratus cloud wedge. By 12 May, the fog-stratus cloud wedge moved northward along the coast of the entire study area as winds in the offshore zone weakened. Both the continental and marine air flow patterns were weak and fog-stratus conditions remained over the coastal regions through 16 May. On 16 and 18 May, two more fronts passed over the study area and by 19 May, the marine layer was established over the study area and stratus conditions existed.

The fourth sequence, 22-30 September, also followed the MFD Model. Like the first sequence, a strong continental air flow over the coast was evaluated, but a persistent marine layer was present offshore so that fog-stratus cloud development was not detected offshore until late in the sequence, on 28 September, and then only 15-25 nm offshore. By 29 and 30 September, the fog layer had been advected shoreward by returning weak northwesterly winds lifting to stratus on 30 May.

In each of these four sequences the evaluated continental and marine air conditions yielded a predictable result. The location of the transitory CCZ and area of fog development appeared to be directly related to

the intensity and direction of continental air flow over the coast, while the persistence of the marine layer tended to influence the offshore extent of the CCZ. The convergence of the two air masses at some location offshore occurred where a relative balance was reached.

IV. CONCLUSIONS

Transient ship observations used in this study, although scarce and subject to problem inconsistencies, errors, and incomplete (missing) data, provided a local reference within the study area on which to base a general description of offshore marine fog-related conditions. Valuable information regarding offshore wind conditions, air mass properties (primarily air temperature) and cloud cover contributed significantly to the descriptive results. On two occasions during the marine fog sequence analyses (10 May and 27 September), ship observations alluded to possible air mass convergence and horizontal mixing and in both cases, marine fog formation occurred downwind of the convergence area.

The Coastal Convergence Zone concept appeared to provide a reasonable approach to tracking the most likely site of marine fog development offshore. The strength and direction of warm dry continental air flow off the coast relative to the prevailing flow of cool moist marine air is instrumental in determining the location of the CCZ. Coastal station observations would provide a local forecaster with sufficient information to adequately evaluate the relative air flow properties that exist over a coastal forecast area via a continuous plot of the fog indices. However, accurate offshore evaluations are dependent on the number and distribution of transient ship observations within the vicinity of the forecast area and the timeliness in which the observations are made available to the forecaster. In the event ship observations were not available, the relative trends of the upwelling index, which reflected the offshore wind conditions quite accurately during this study, could be used to supplement

a forecaster's evaluation of the offshore atmospheric conditions. By combining the coastal and offshore air mass evaluations with satellite photograph and synoptic analysis interpretations, the forecaster should be able to observe or estimate the location and movements of the CCZ.

V. RECOMMENDATIONS

In marine fog studies that utilize transient ship data, it is suggested that the researcher establish personal contact with qualified personnel from the source that will be supplying the data. Information regarding known problems with the requested data is considered essential in establishing the scope of the study.

A significant limitation to marine fog studies is the lack of offshore upper air data. A possible solution would be for agencies, interested in fog research, to contact departing ships and arrange for radiosonde equipment, supplied by the research agency, to be launched at a predetermined time or location and monitored from a coastal station. One or two offshore radiosonde soundings daily would be helpful in describing offshore atmospheric conditions.

Further investigation into the Coastal Convergence Zone concept would aid a better understanding of marine fog development. One avenue of research would be to look at the possible formation mechanisms. The CCZ may be the result of boundary or gravity wave phenomena or a frontal (transition) zone development. The convergence aspect of the CCZ provides another area of interest. Observations made during this study alluded to horizontal mixing of air masses and fog formation downwind of the evaluated convergence area during phase two and three. Pilie et al (1976) proposed vertical motion as the result of air mass convergence. It is possible that both horizontal and vertical motion occur or there may be some critical angle at which the air masses must converge in order to induce vertical motion.

APPENDIX A

MARINE FOG DEVELOPMENT MODEL SUMMARY

APPENDIX A

MARINE FOG DEVELOPMENT MODEL SUMMARY

PHASE ZERO - No thermal inversion below 400 m, surface air temperature at or very near sea-surface temperature.

- Synoptic apercu

    1> Eastern Pacific Ocean atmospheric circulation pattern dominated by subtropical Pacific High;

    2> Pacific High and associated high pressure ridge instrumental in deflecting and/or weakening frontal systems that approach the California coast.

- Mesoscale synopsis for central California coast

    3> Isobar alignment is meridional;

    4> prevailing winds are northwesterly;

    5> marine layer established over both the offshore and coastal areas, usually restricted to below 700 m;

    6> upper air subsidence inversion of warm dry air over the marine layer, stratus may be present with the cloud top at about the height of the inversion base;

    7> coastal temperature and moisture index values reflect relatively cool and moist air present over the coastal regions, upwelling index value relatively high.

PHASE ONE - No thermal inversion below 400 m, surface air temperature greater than the sea-surface temperature.

- Synoptic apercu

    1> Pacific High migrates to the northeast towards the Pacific northwestern states where it may continue inland, split and/or retreat to the southwest, or;

    2> Pacific High weakens offshore and a thermal trough extends northward into the interior of central California, or;

    3> a combination of 1> and 2>.

- Mesoscale synopsis for central California coast

    4> Isobar alignment veers to near a northeast-southwest orientation;

5> offshore winds weaken and veer northward, coastal winds are weak with an easterly component resulting in a flow of warm dry continental air over the coastal area (which may dissipate the stratus and produce clear skies);

6> coastal temperature and moisture index values initiate trends connotative of warm dry air flow into the coastal area, upwelling index decreases;

7> the CCZ is in an early stage of development with the extent and relative location (inland, coastal, nearshore or offshore) dependent upon the strength of the continental air flow over the coastal area.

PHASE TWO - Thermal inversion is formed at the surface, surface air temperature greater than the sea-surface temperature.

- Synoptic apercu

1> Pacific High retreats back to the southwest over the Eastern Pacific Ocean, or;

2> a freshening subtropical Pacific High is introduced in the Eastern Pacific Ocean, and;

3> the thermal trough moves westward over the California coast.

- Mesoscale synopsis for central California coast

4> Isobar alignment continues to veer until orientation is nearly east-west as the thermal trough dominates the coastal regions;

5> easterly winds increase over the coastal area resulting in an increased flow of continental air over the coast and nearshore zones, offshore winds (seaward of nearshore zone) remain weak and northwesterly;

6> the CCZ is strengthening in the nearshore zone with the seaward edge located in the vicinity of where continental air and marine air masses converge; the moisture content of the continental air seaward of the coast increases to near saturation at the surface;

7> coastal temperature and moisture index values continue warming trend and the upwelling index reaches a relative minimum value.

PHASE THREE - thermal inversion deepens, surface air temperature decreases to below the sea-surface temperature.

- Synoptic apercu

1> Pacific High strengthens offshore resuming dominance of the atmospheric circulation over the Eastern Pacific Ocean;

2> thermal trough is displaced eastward over the interior of southern California.

- Mesoscale synopsis for central California coast

3> Isobar alignment is meridional;

4> weak prevailing northwest winds return to the nearshore zone, easterly winds over the coastal zone weaken and the flow of continental air decreases;

5> the CCZ, with the lower layer near saturation, is advected shoreward over colder coastal water where fog is produced (by cooling from below); the CCZ now becomes defined by the fog layer, radiational cooling from the cloud tops cools the fog layer further and convergence of marine air and continental air masses produces vertical motion and mixing within the fog layer, which increases the fog layer depth;

6> coastal temperature and moisture index values reverse trends reflecting the presence of cooler, moist air over the coast, upwelling index value increases;

7> fog or stratus occurs over the coast, normally advected inland commencing late-afternoon by the sea breeze as the coastal land mass begins to cool.

PHASE FOUR - thermal inversion lifts from the surface, surface air temperature approaches the sea-surface temperature, phase termination occurs when base of inversion lifts above 400 m.

- Synoptic apercu

1> Pacific High dominates the atmospheric circulation pattern over the Eastern Pacific Ocean;

2> thermal trough displaced further inland and ceases to contribute continental air flow to the coastal region.

- Mesoscale synopsis for central California coast

3> Isobar alignment is meridional;

4> prevailing northwesterly winds strengthen over nearshore and coastal zones;

5> moist marine air flows onshore beneath the lifting thermal inversion, fog no longer forms at the surface and the fog layer lifts until stratus overcast remains;

6> coastal temperature and moisture index values approach phase zero values and upwelling index value reaches relative maximum value.

APPENDIX B

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

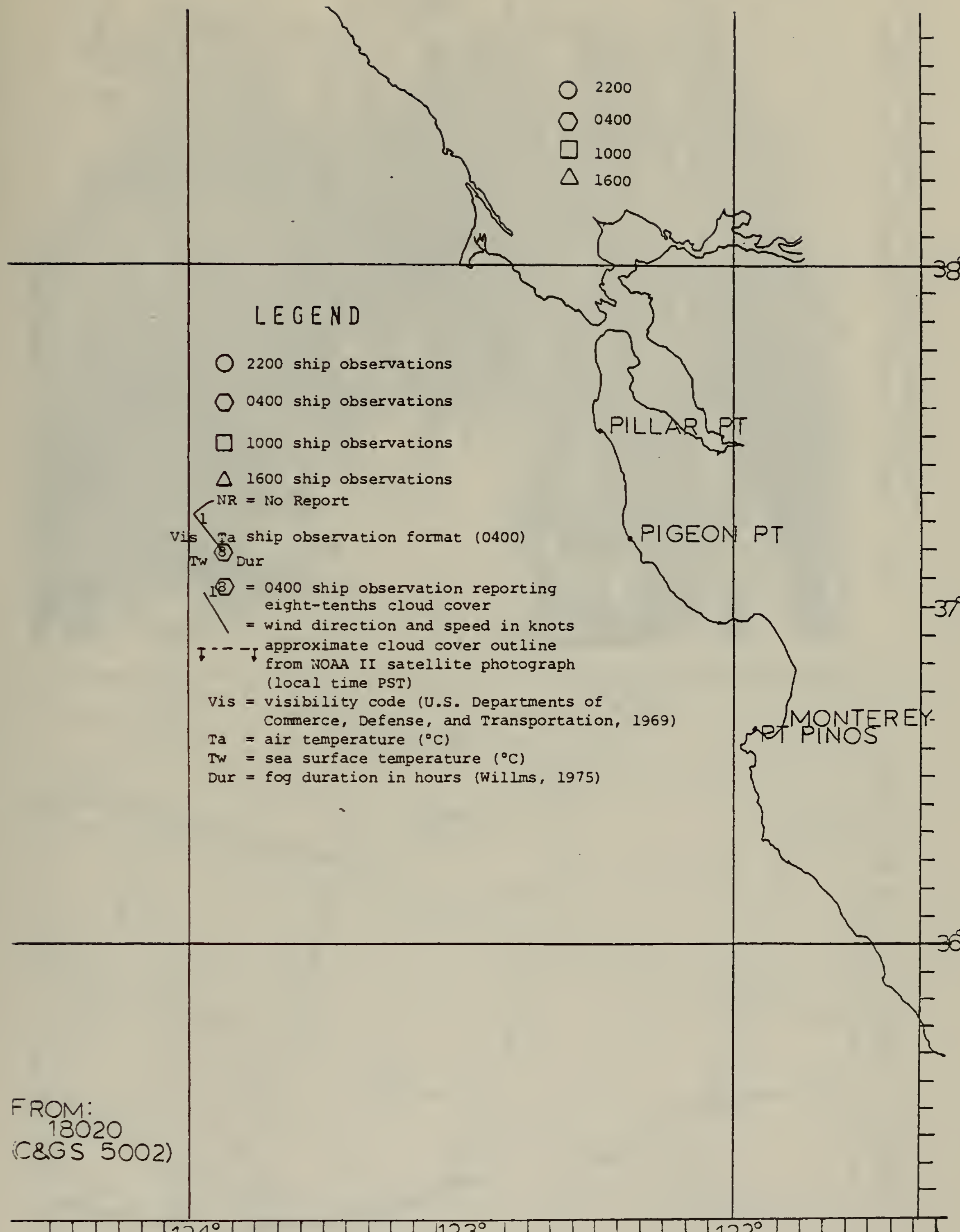
25-31 May, 1973

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

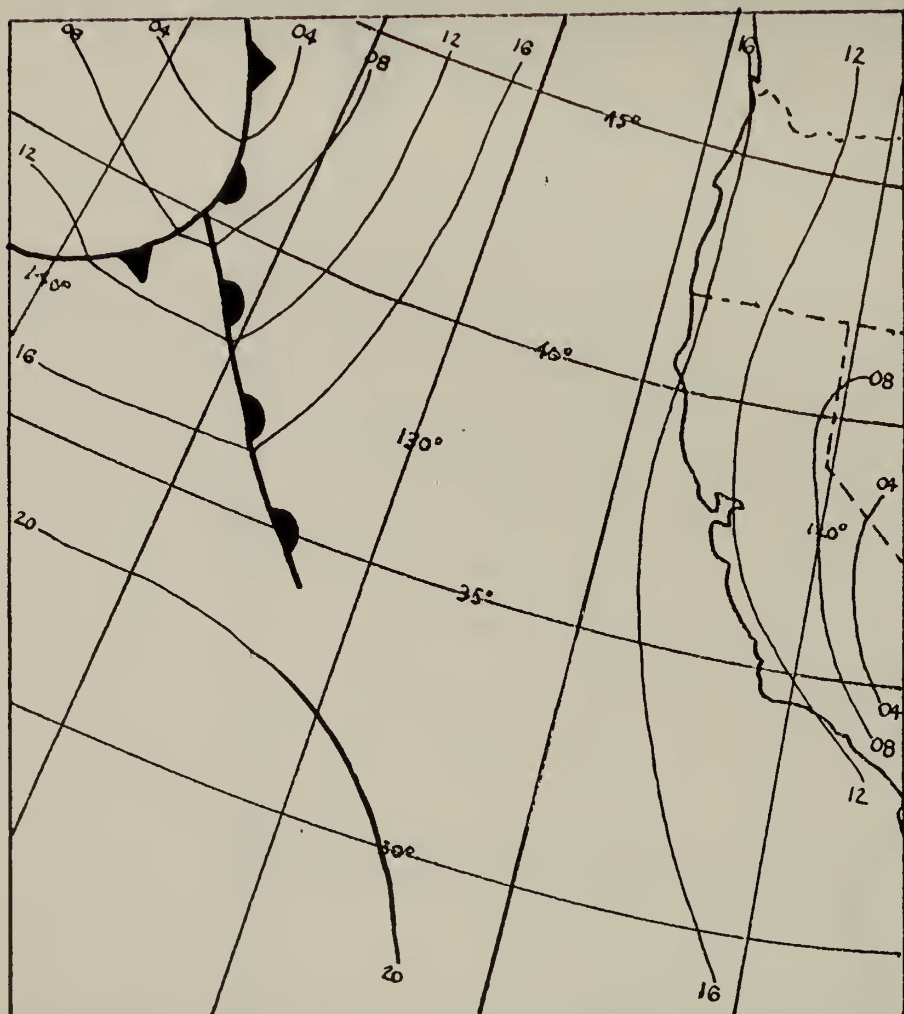
Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Ph	Model Status Loc of CCZ	Ship Data Winds	Ship Data Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
25-31	May	1973										
25	0		=NNW20	10+/Clear	Clear offshore.	0	50	-3	1	x	x	190
	Remarks: Synoptic conditions constant over last four days except for frontal passage over central California late 24 May (effects still evident in Oakland 0400 sounding) leaving study area clear											
26	1	Inl	NNW 5-20	10+/NSA-5/10	Clear offshore, frontal system and associated cloud formation otherwise clear near western edge of study area.	1	600	-4	-1	x	x	100
	Remarks: Eastern Pacific H moved eastward pushing tongue of high pressure inland, isobars meridional, weakening of offshore winds. Later in day, coastal indices indicated warming trend, UI reflects offshore wind reduction. Occluded frontal system west of study area appears to have dissipated offshore.											
27	2	Co and Nsh	NNW 5-10	10+/MSA-4/10	Thin stratus cloud scattered 20-30 nm offshore, possibly remnants of dissipated frontal system from previous day.	2	Sfc	4	3	x	x	80
	Remarks: Pacific H moved rapidly to NE mid-day, thermal trough extended weakly into southern California, isobar alignment generally NE-SW over central California. Coastal indices continued warming trend.											
28	2	Ofs 40-60nm	NE = 5	10+/MSA-9/10 (100 nm east of coast)	Well defined fog-stratus cloud 40-50 nm offshore, clear air band near coast and inland.	2	Sfc	5 M	12	x	x	50 m
	Remarks: Thermal trough overlapping California coast controlled air circulation over study area, coastal indices at or near extreme values.											

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

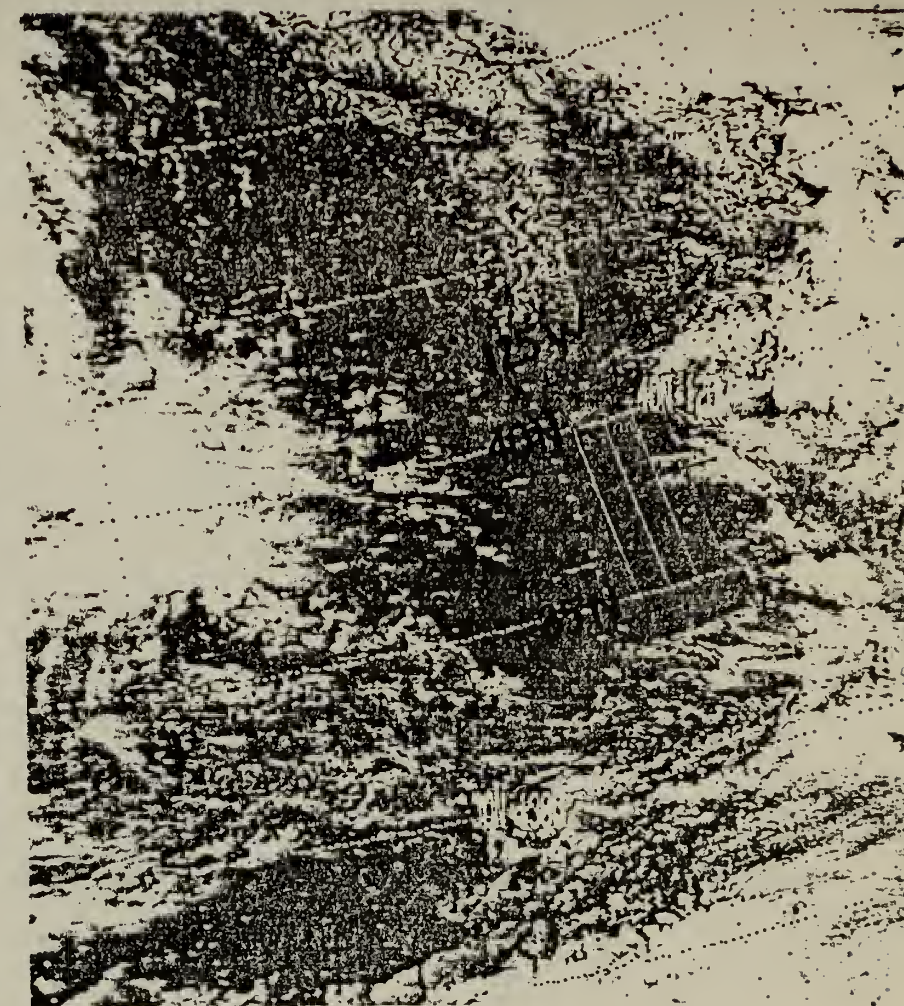
Date	MFD Ph	Model Status Loc of CCZ	Ship Data Winds	Ship Data Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
25-31 May (continued)												
29	3	Nsh	=NNW5	X	Well defined fog-stratus cloud along coast NSA, near-coast, MSA and SSA. Clear west of study area.	2	Sfc	2	15	80	28	140
	Remarks: Pacific H generated EASTPAC, pushed thermal trough inland, return of weak NW winds, advected CCZ (now fog layer) shoreward. Coastal indices reach extreme value or begin reversing (cooling) trend. UI reflects return of NW winds.					Fog present at all four coastal staions commencing in afternoon.						
30	3	Nsh-Co	W/5	10+/8/10-10/10 Fogger	Complete cloud cover over entire offshore and most of coastal portion of study area.	3	150	2	14	62	52	240
	Remarks: Pacific H continued to establish circulation dominance, thermal trough further inland. Inversion lifted from surface, and coastal indices continued cooling trends.					Fog present all coastal stations most of day, overcast conditions prevail otherwise.						
31	4	Co	=NW10	10+/8/10-10/10	Complete cloud cover over ehtire study area.	4	750	1	7	60	x	160
	Remarks: Pacific H dominates synoptic circulation over California coast.					Overcast reported most of day by all coastal stations.						



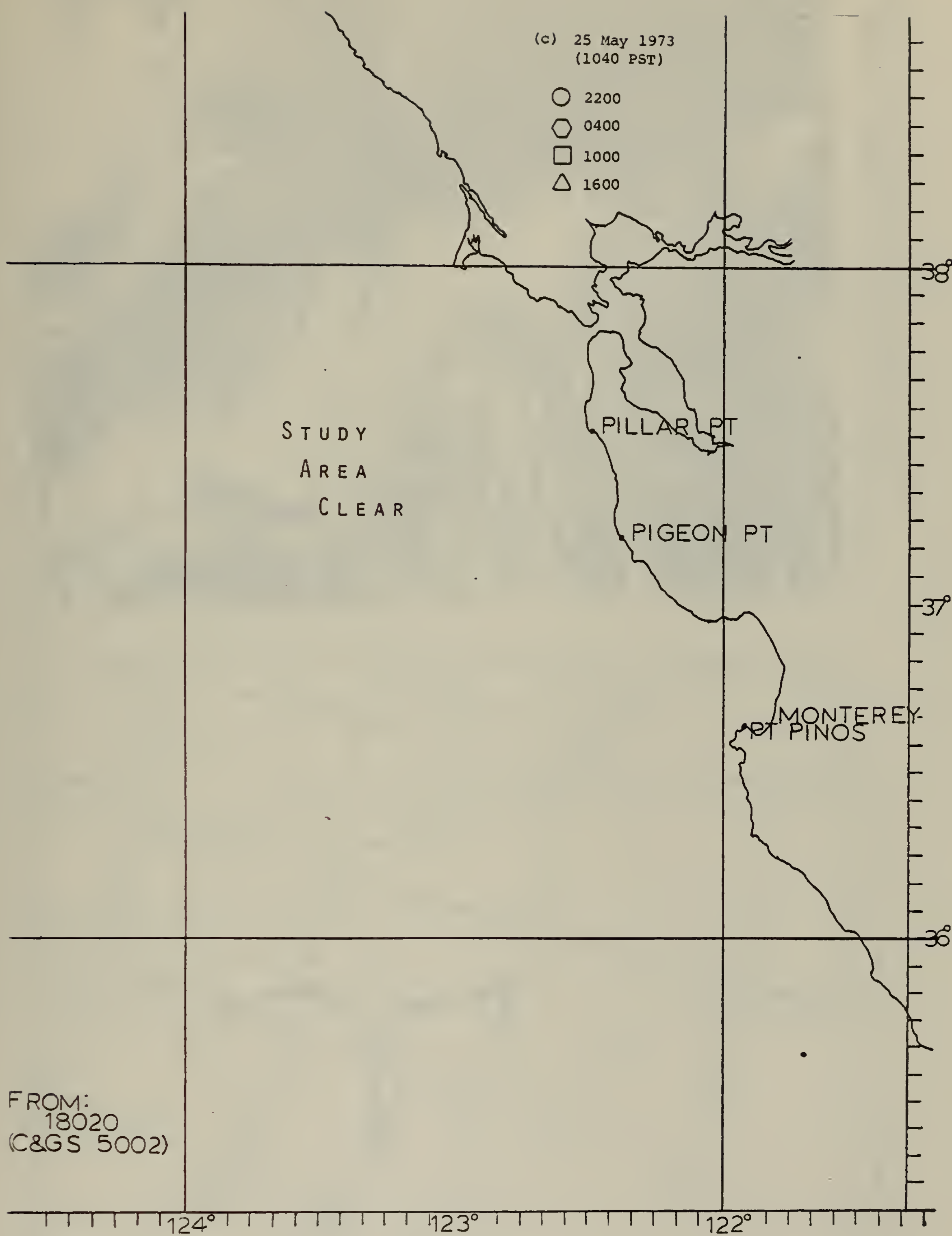
2200
0400
1000
1600
LEGEND
2200 ship observations
0400 ship observations
1000 ship observations
1600 ship observations
NR = No Report
Vis Ta ship observation format (0400)
Tw Dur
= 0400 ship observation reporting eight-tenths cloud cover
= wind direction and speed in knots
approximate cloud cover outline from NOAA II satellite photograph (local time PST)
Vis = visibility code (U.S. Departments of Commerce, Defense, and Transportation, 1969)
Ta = air temperature (°C)
Tw = sea surface temperature (°C)
Dur = fog duration in hours (Willms, 1975)
PILLAR PT
PIGEON PT
MONTEREY
PT PINOS
38°
37°
36°
124°
123°
122°
FROM:
18020
(C&GS 5002)



(a) NMC Final Analysis - 1000 PST - 25 May 1973



(b) NOAA II Satellite Photograph of Study Area off the West Coast at 1040 PST, 25 May 1973



(c) 25 May 1973
(1040 PST)
2200
0400
1000
1600
STUDY
AREA
CLEAR
PILLAR PT
PIGEON PT
MONTEREY
PT PINOS
38°
37°
36°
124°
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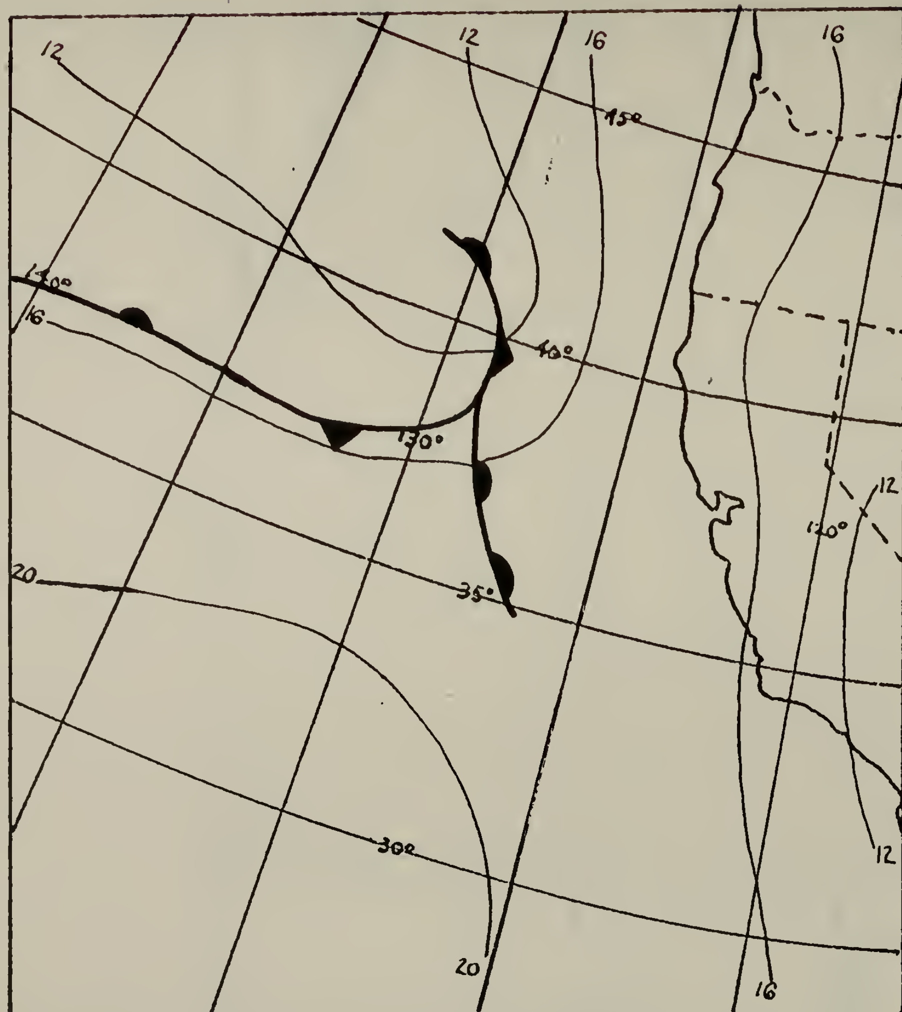
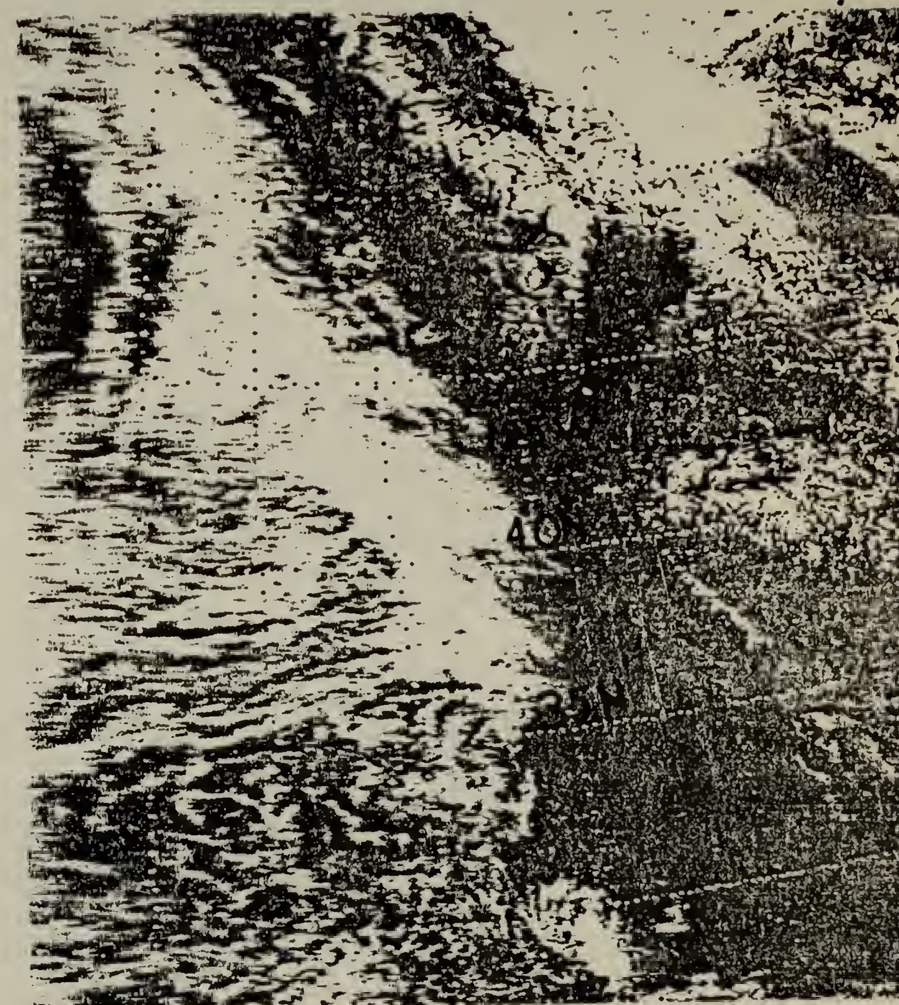
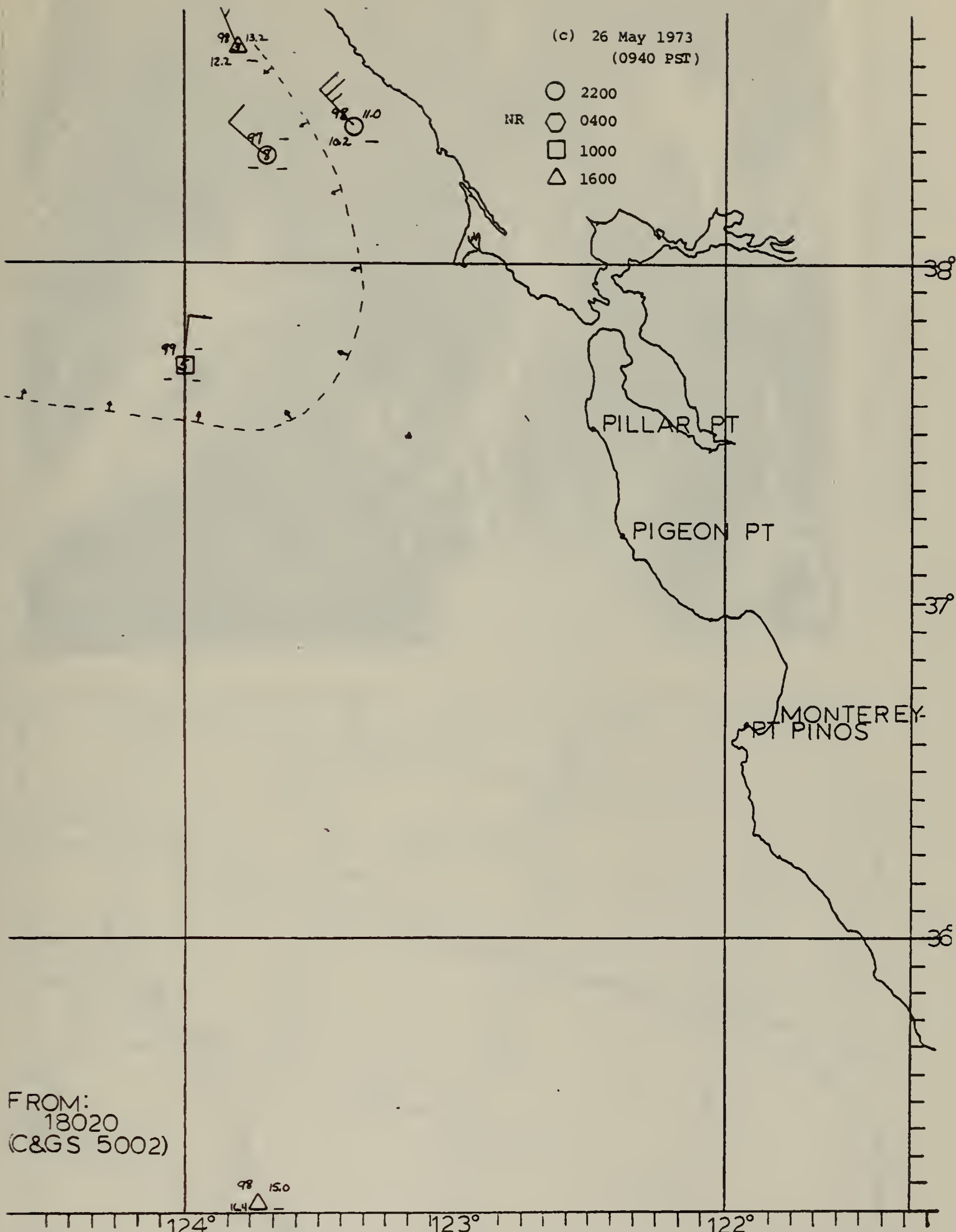
122°
FROM:
18020
(C&GS 5002)



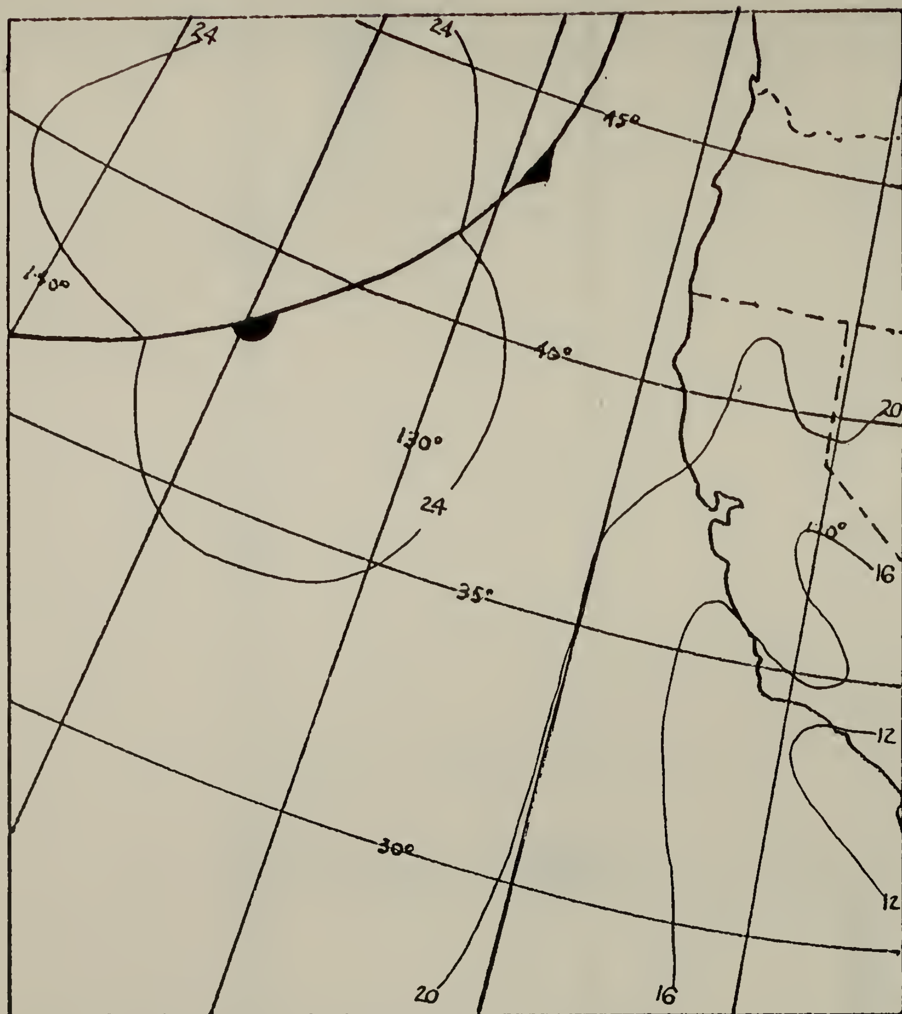
(a) NMC Final Analysis - 1000 PST - 26 May 1973



(b) NOAA II Satellite Photograph of Study Area off the West Coast at 0940 PST, 26 May 1973

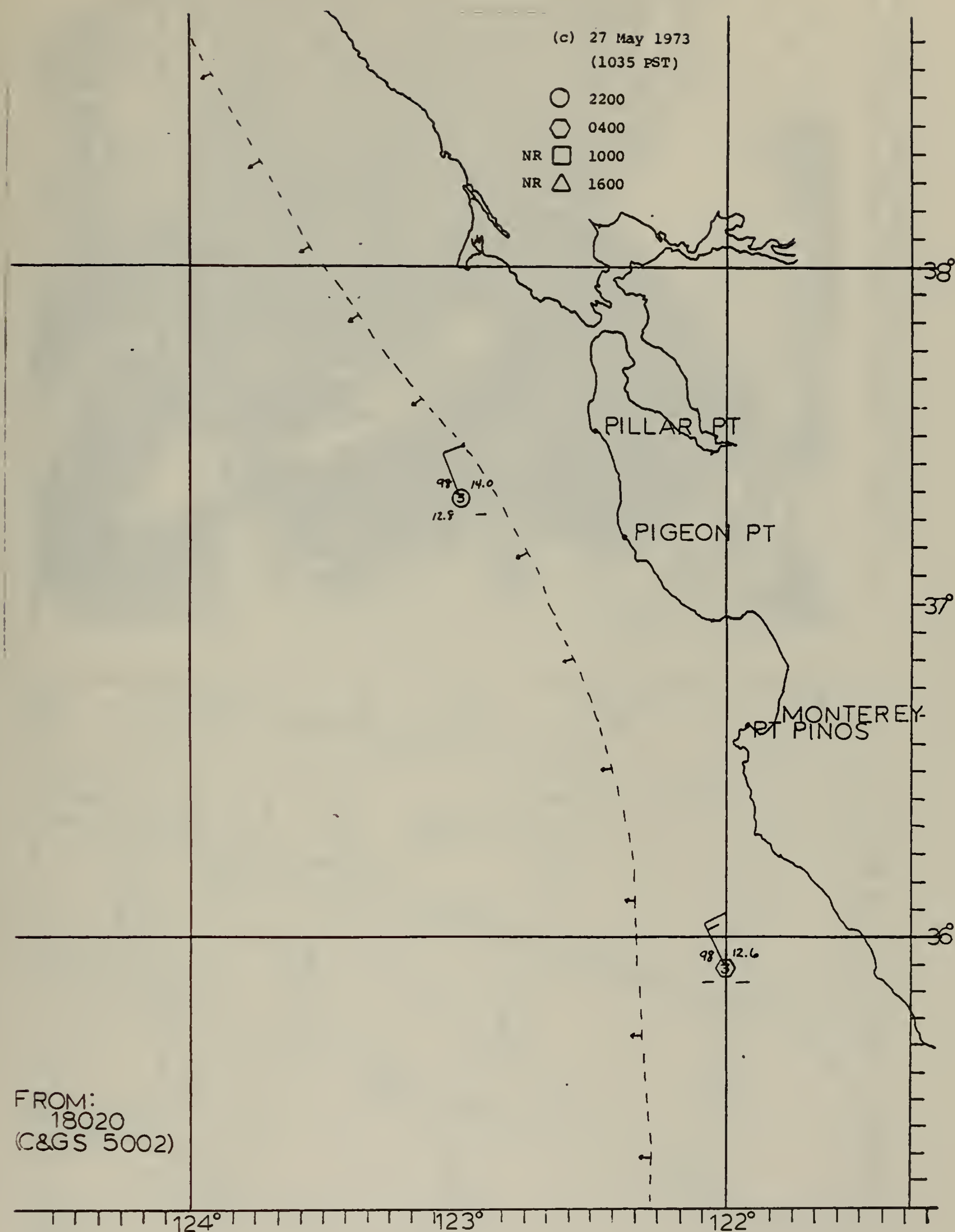


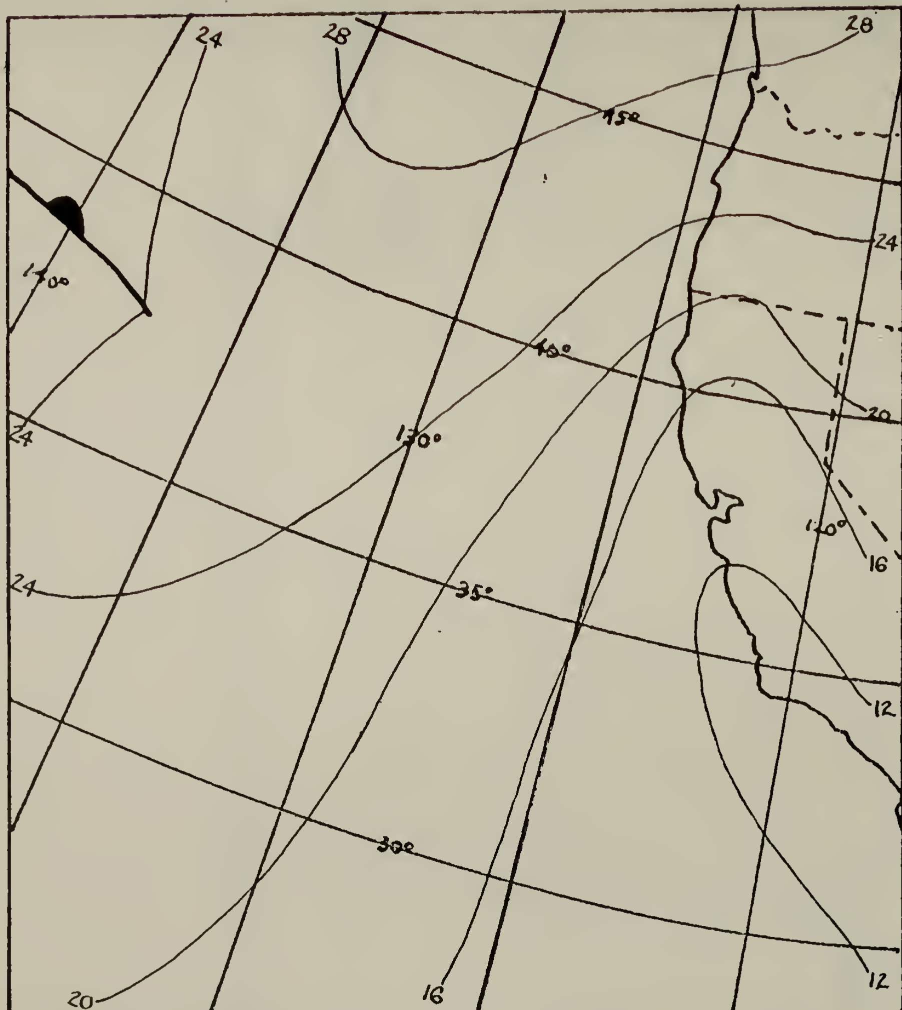
(c) 26 May 1973
(0940 PST)
2200
NR 0400
1000
1600
PILLAR PT
PIGEON PT
MONTEREY
PT PINOS
38°
37°
36°
124°
123°
122°
FROM:
18020
(C&GS 5002)



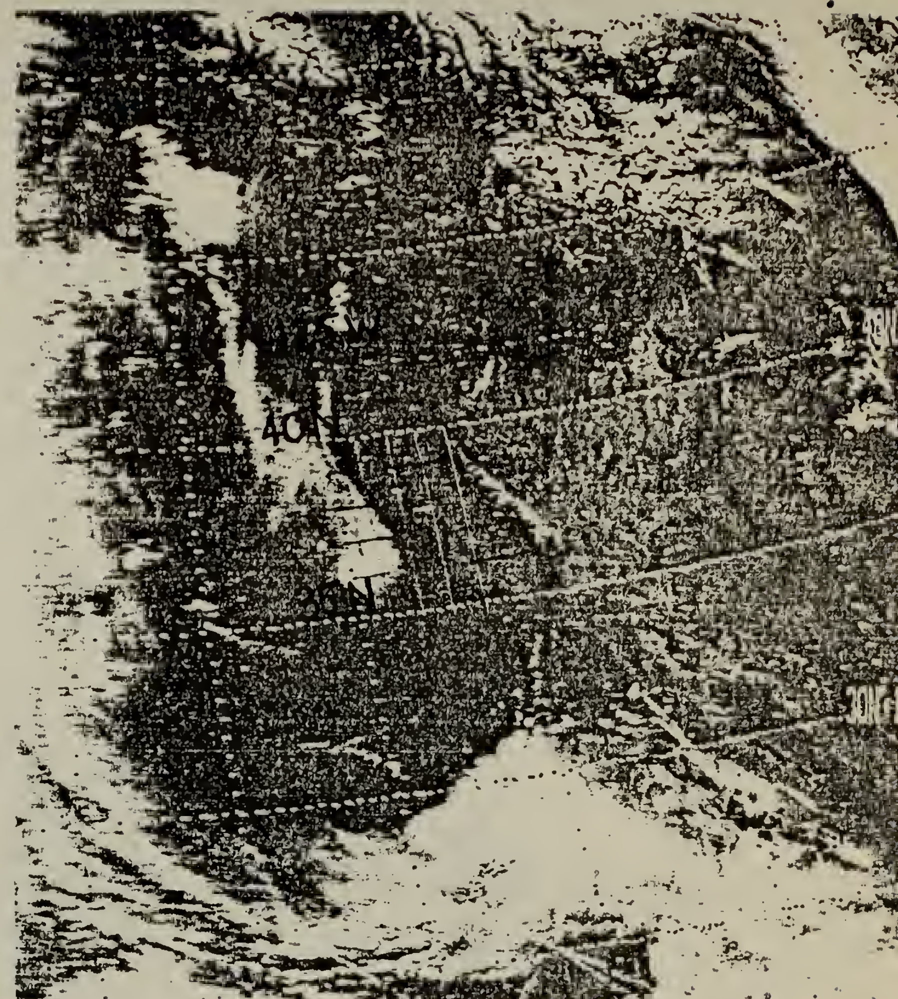
(a) NMC Final Analysis - 1000 PST - 27 May 1973

(b) NOAA II Satellite Photograph of Study Area off the West Coast at 1035 PST, 27 May 1973

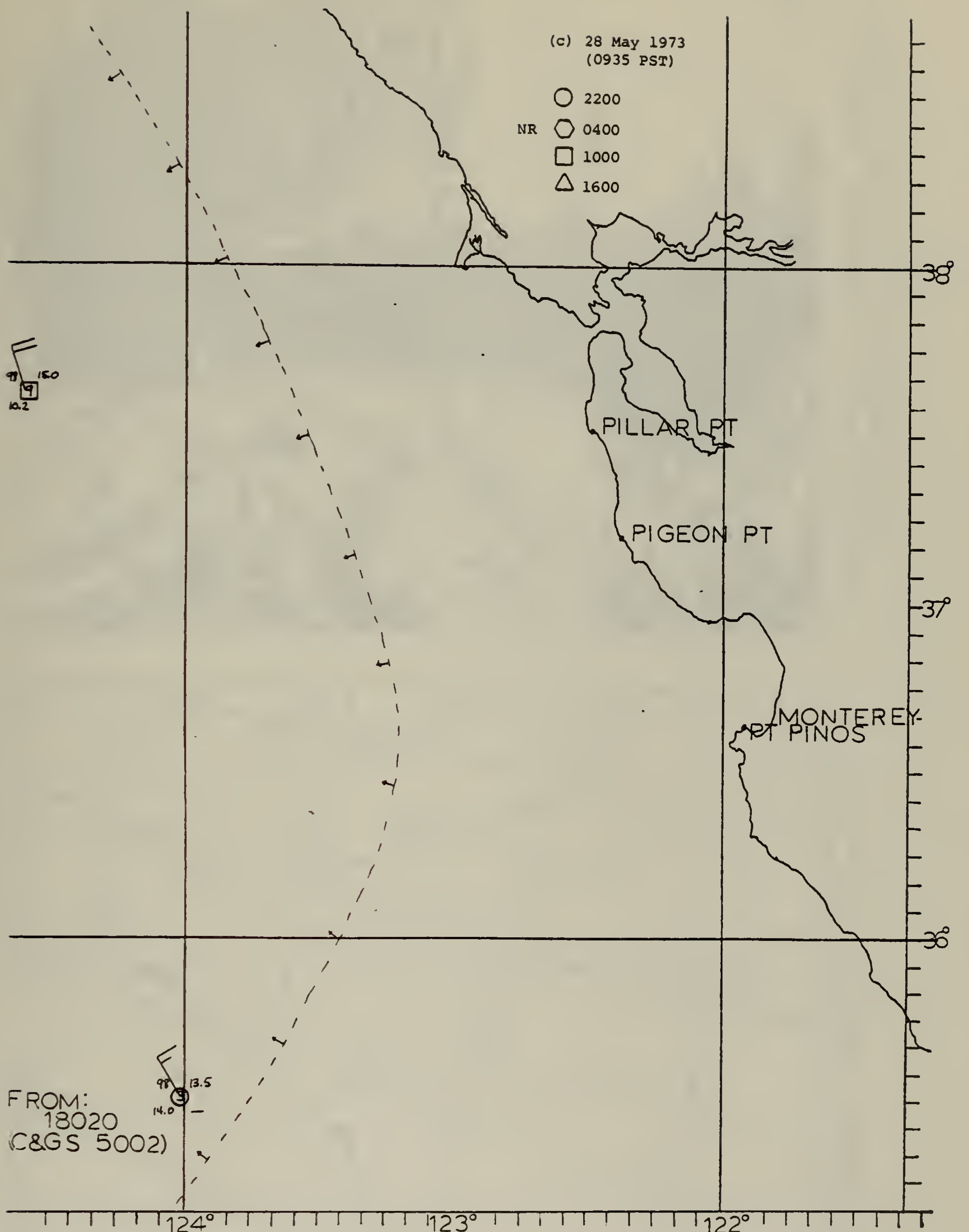

(c) 27 May 1973
(1035 PST)
2200
0400
NR 1000
NR 1600
38°
PILLAR PT
PIGEON PT
37°
MONTEREY
PT PINOS
36°
FROM:
18020
(C&GS 5002)
124°
123°
122°



(a) NMC Final Analysis - 1000 PST - 28 May 1973



(b) NOAA II Satellite Photograph of Study Area off the West Coast at 0935 PST, 28 May 1973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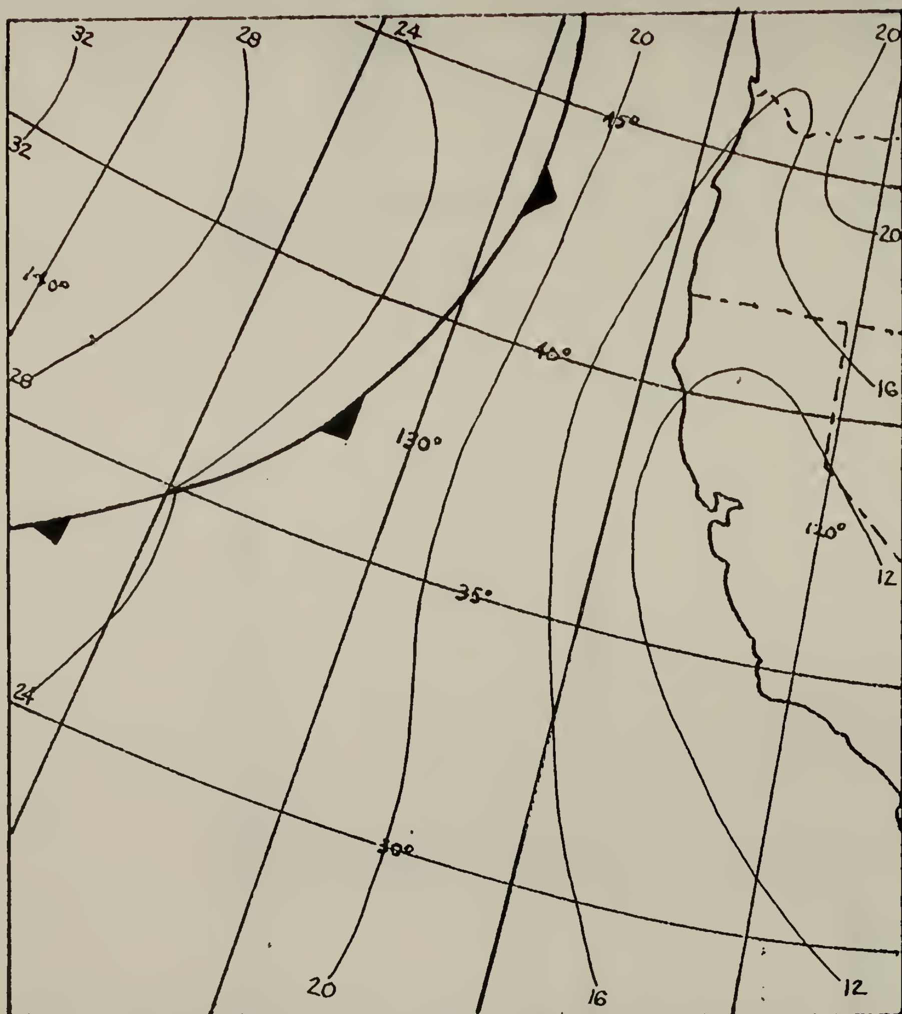
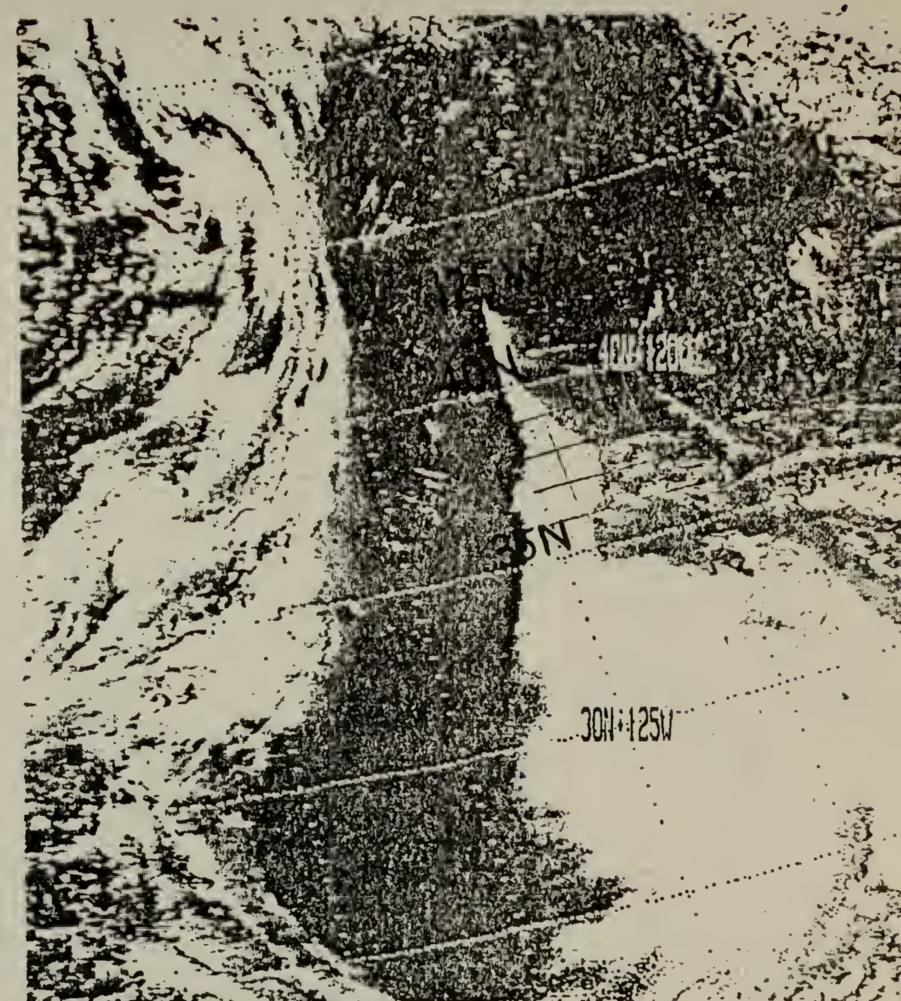
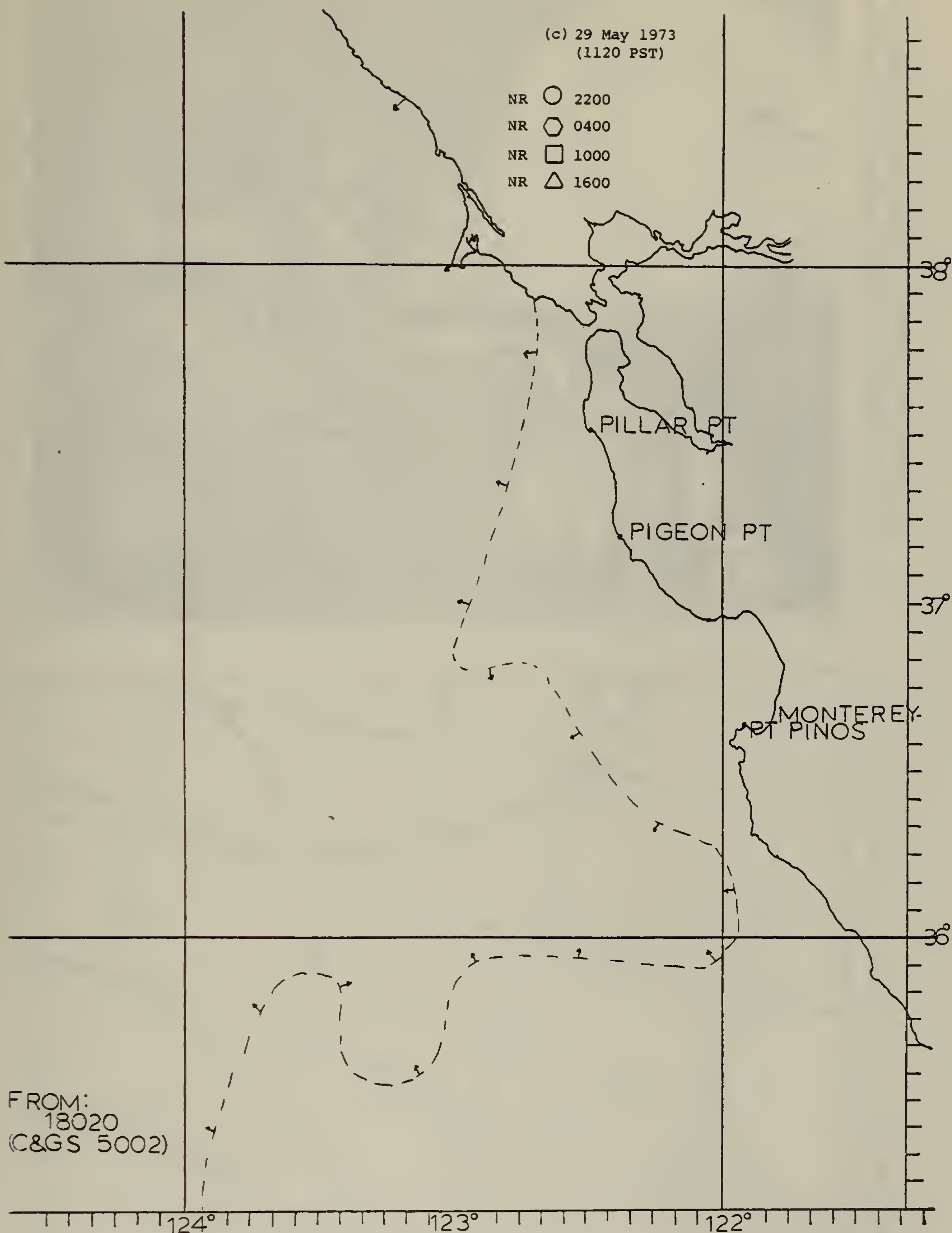
(0935 PST)
2200
NR 0400
1000
1600
38°
PILLAR PT
PIGEON PT
37°
MONTEREY
PT PINOS
36°
FROM:
18020
(C&GS 5002)
124°
123°
122°



(a) NMC Final Analysis - 1000 PST - 29 May 1973



(b) NOAA II Satellite Photograph of Study Area off the West Coast at 1030 PST, 29 May 1973



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(1120 PST)
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NR 0400
NR 1000
NR 1600
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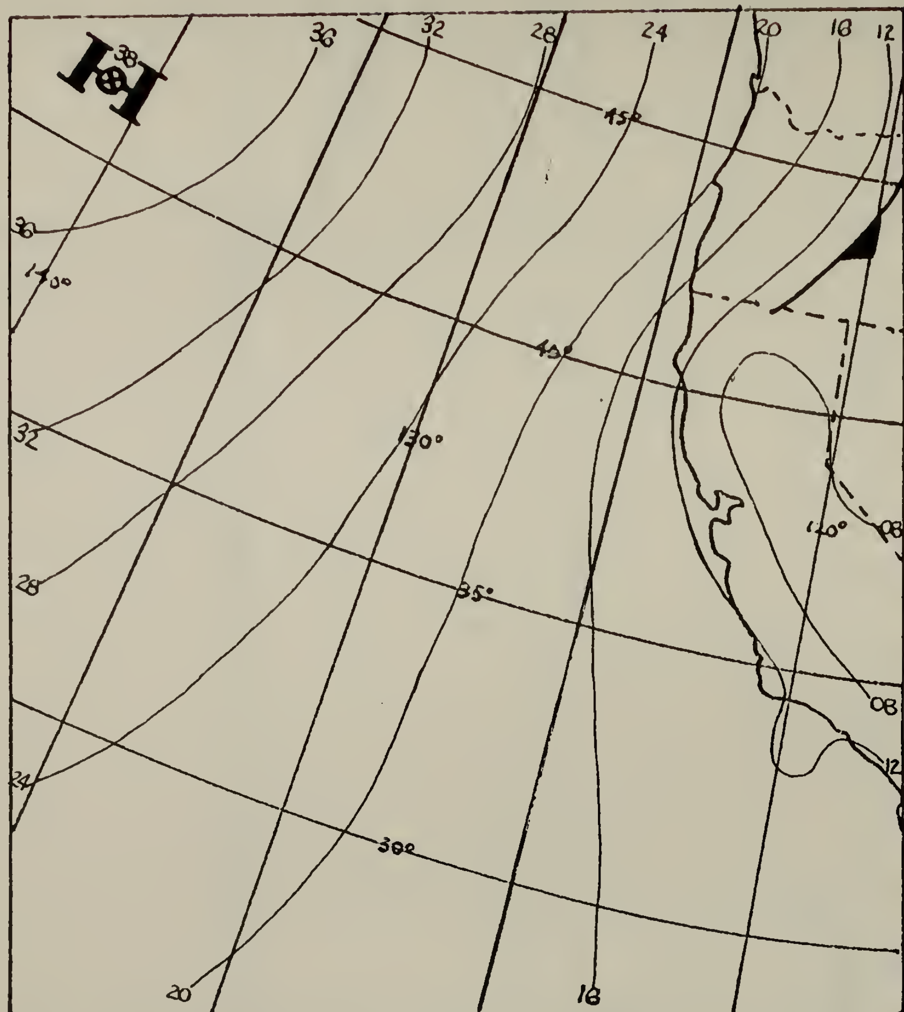
PILLAR PT
PIGEON PT
37°
MONTEREY
PT PINOS
36°
FROM:
18020
(C&GS 5002)
124°
123°
122°



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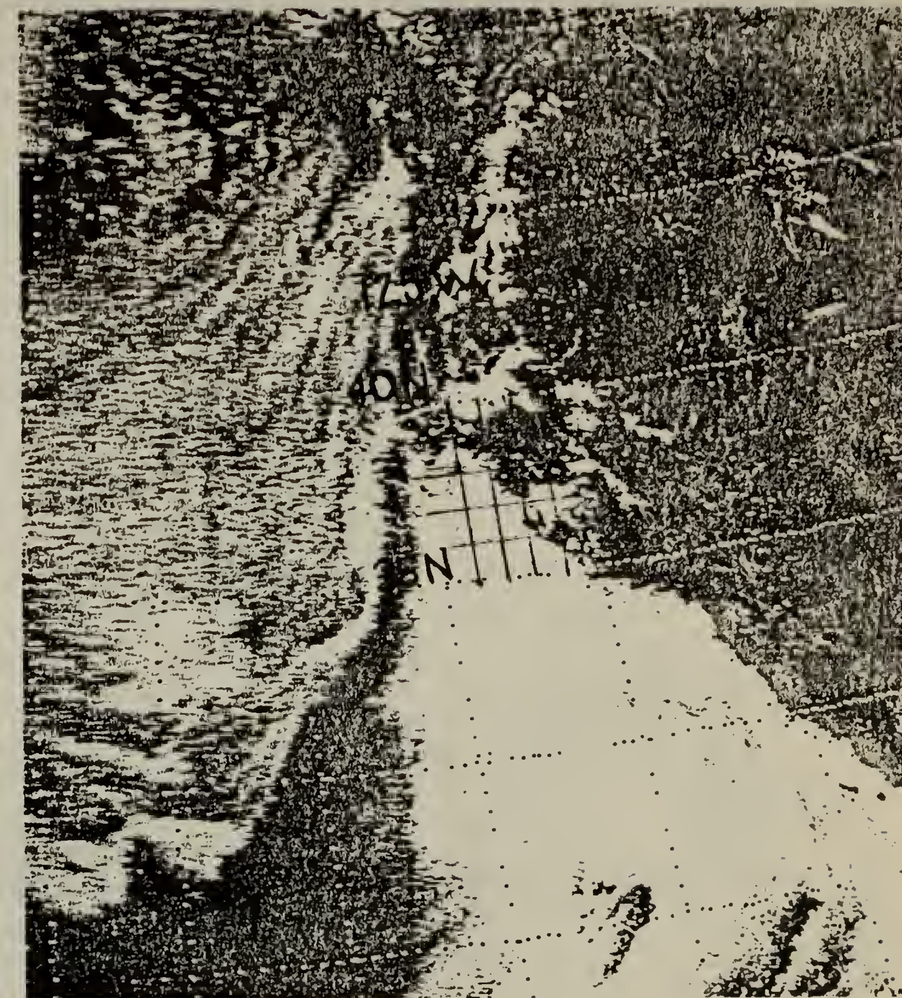
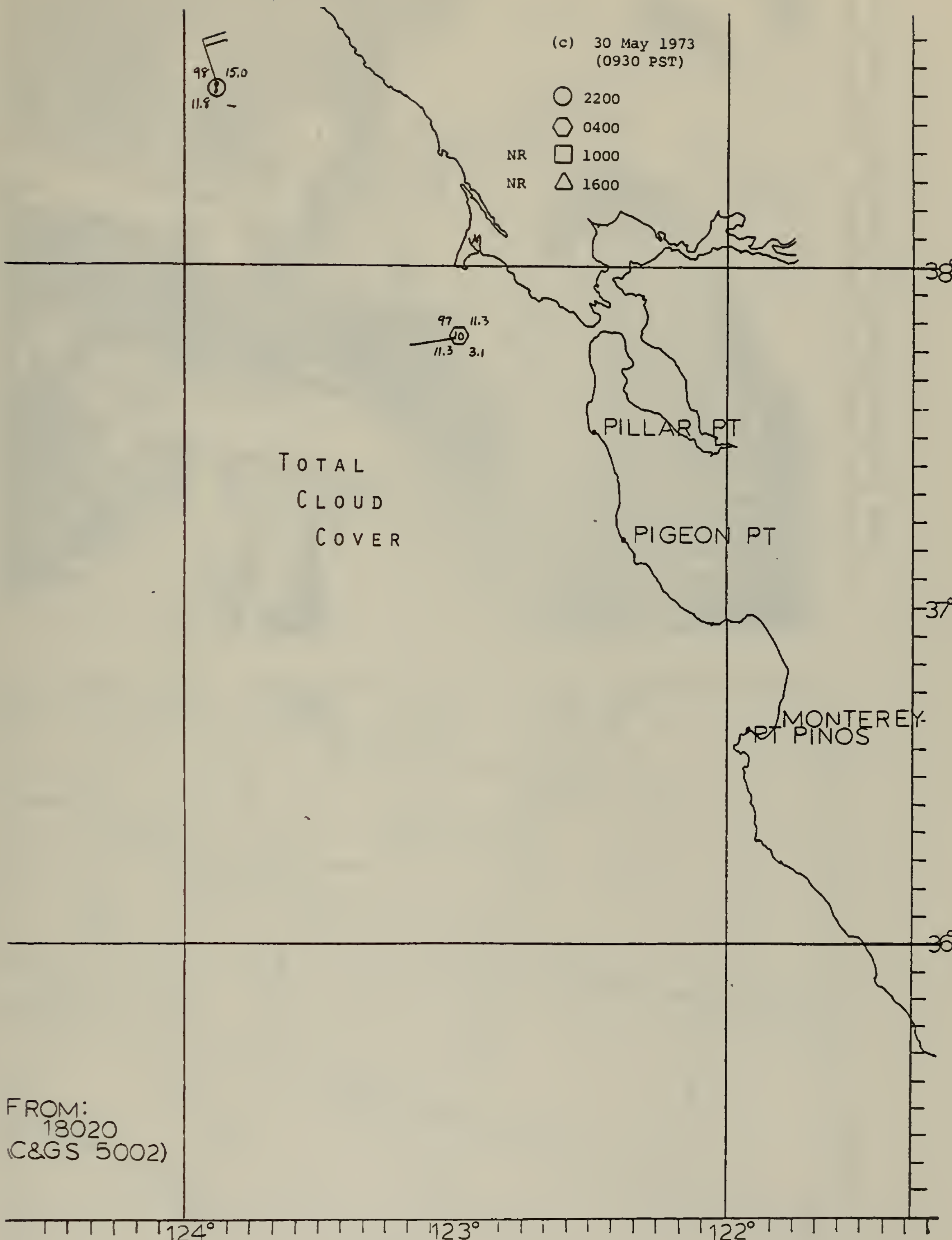


(b) NOAA II Satellite Photograph of Study Area off the West Coast at 0930 PST, 30 May 1973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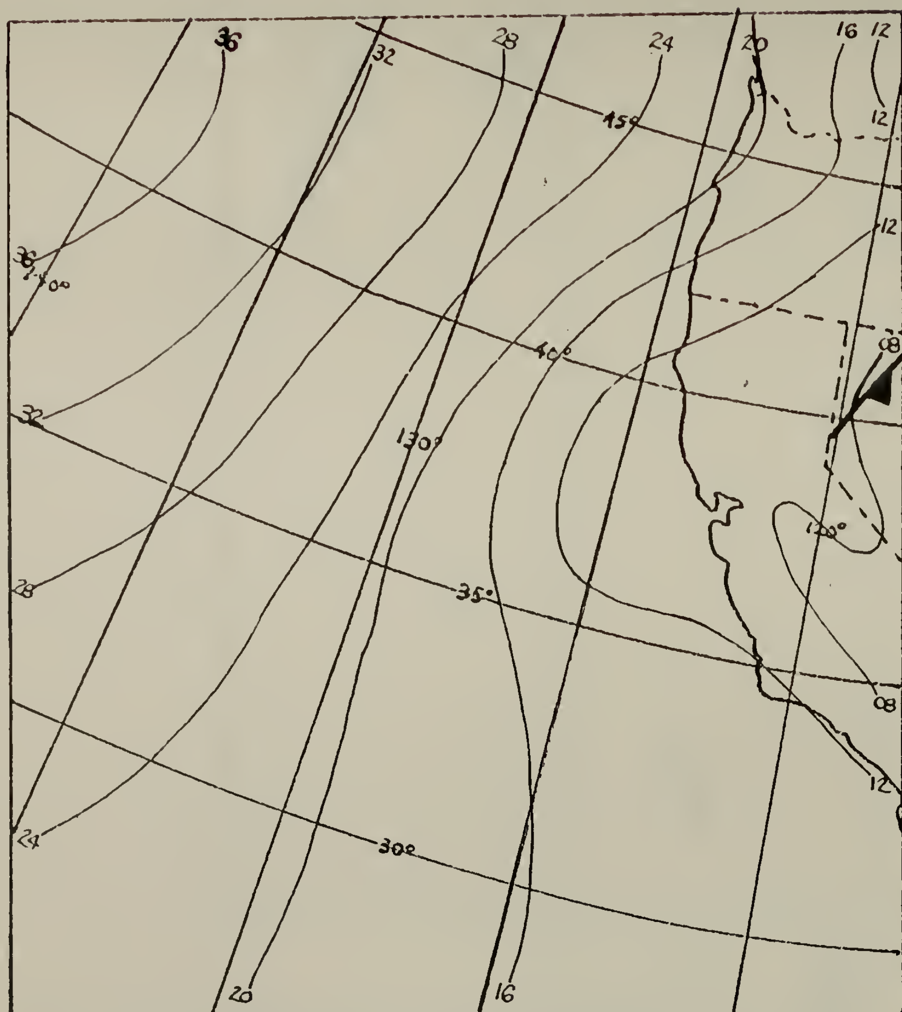
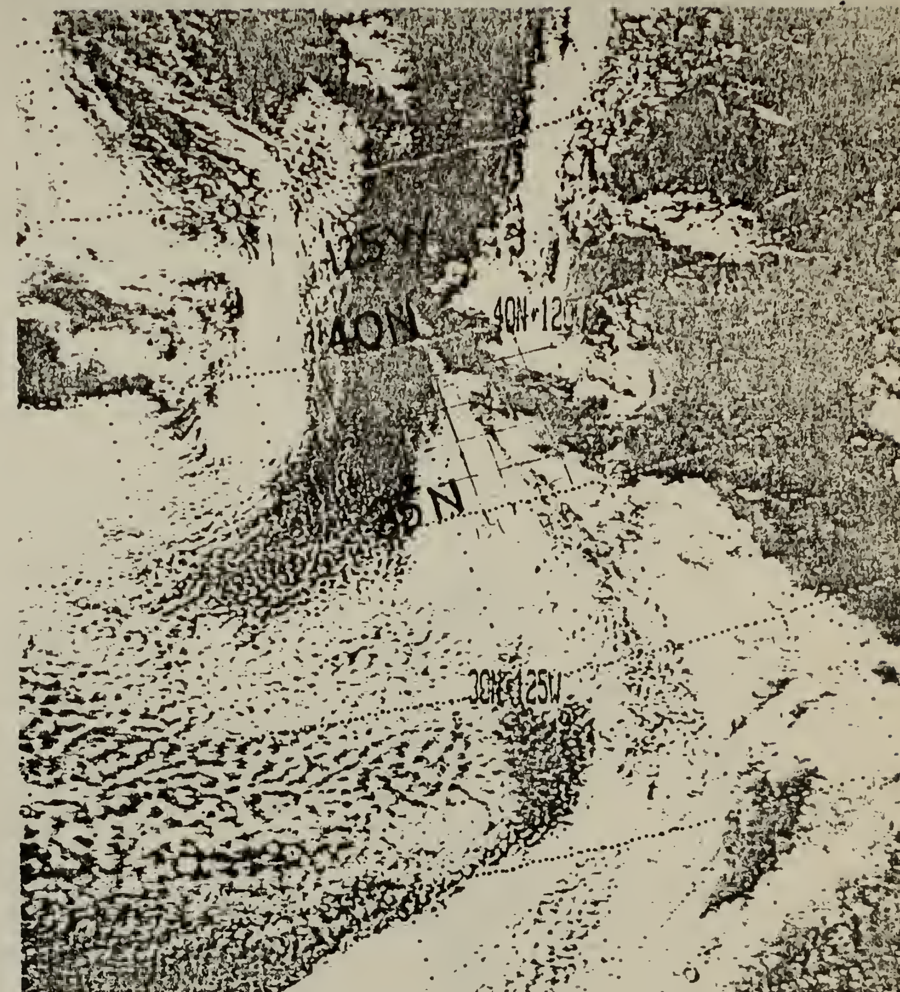
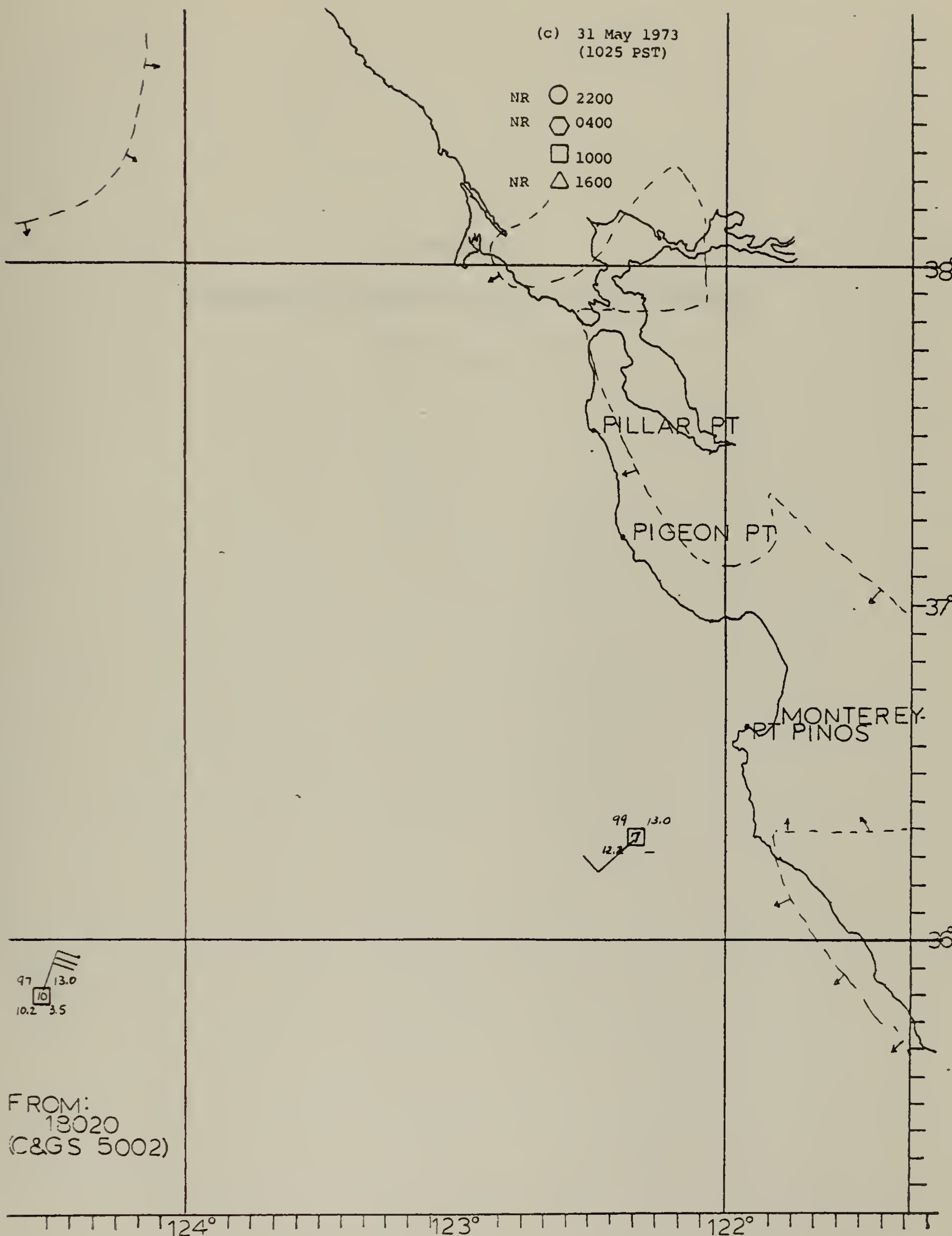
(0930 PST)
2200
0400
NR 1000
NR 1600
PILLAR PT
PIGEON PT
MONTEREY
PT PINOS
TOTAL
CLOUD
COVER
38°
37°
36°
124°
123°
122°
FROM:
18020
(C&GS 5002)



(a) NMC Final Analysis - 1000 PST - 31 May 1973



(b) NOAA II Satellite Photograph of Study Area off the West Coast at 1025 PST, 31 May 1973


(c) 31 May 1973
(1025 PST)
NR 2200
NR 0400
1000
NR 1600
PILLAR PT
PIGEON PT
MONTEREY
PT PINOS
FROM:
18020
(C&GS 5002)
124°
123°
122°
38°
37°
36°

APPENDIX C

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

18-29 April 1973

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Date	MFD Model Status Ph	MFD Model Status Loc of CCZ	Ship Data Winds	Ship Data Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Offshore Data					Coastal Data (Beardsley, 1976)						
18-29 April 1973												
18	0		NW20	10+/1/10	Study area clear ahead of frontal system.	0	750	-3	-2	52	44	320
	Remarks: Pacific H dominates air circulation over EASTPAC, ridge of high pressure NW Pacific states cause isobar alignment to be meridional. Approach of frontal system towards coast steered to SE, crosses central California late evening.											
19	0		NW 15-30	10+/1/10	Study area clear after frontal passage.	1	1050	-4	-1	53	43	340
	Remarks: Pacific H moving northward after frontal passage with a ridge of high pressure extending northward over NW Pacific States and Canada. Isobar alignment is meridional and shifting to NNE-SSW. Slight temperature increase recorded by Oakland radiosonde sounding.											
20	1	Co	NW 15-25	10+/clear	Study area clear.	2	Sfc	-10	2	61	16	200
	Remarks: Pacific H continues migration towards NNE. Weak thermal trough overlaps southern California coast. Isobar alignment NE-SW across central California. Coastal indices indicate presence of warm air over coastal regions.											
21	2	NCo	NNW 5-15	10+/Clear	X	2	Sfc	-2	5	70	8	65
	Remarks: Migration of Pacific H retarded by advance of frontal system out of northern Pacific Ocean, Pacific H retreats slightly to SW, ridge extends over NW Pacific states. Thermal trough overlaps California coast, isobar alignment E-W over northern California, meridional over central California and offshore areas. Coastal indices continue warming trend.											

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status Ph	MFD Model Status Loc of CCZ	Ship Data Winds	Ship Data Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
18-29 April (continued)												
22	2	NCo	NNW weak-10 or calm*	10+/clear-6/10*	A very light fog-stratus cloud formation from Pt Reyes south to Pt Pinos.* Remainder of study area clear. Frontal system associated cloud formation located at NW corner of study area.	2	Sfc	-1	8	74	8	120
Remarks: Pacific H continuing migration to NE behind frontal system thermal trough over inland central California. Frontal system passed over central California late afternoon.												
23	2	NCo	NW 15-25	NSA lot/clear MSA lot/5/10*	Low cloud type formation about 10 nm offshore vicinity of Monterey Bay southward,* southern half of study area covered by cellular-cumulus type cloud formation.	2	Sfc	-1	2	61	48	220
Remarks: Pacific H stationary over EASTPAC as another frontal system approaches from the north. Ridge extends NE into NW Pacific states, thermal trough extends over northern California. Isobar alignment NE-SW over northern California bending to parallel central California coast.						Observe reversal (cooling) trend of coastal indices and increase of UI associated with the frontal system passage.						
24	2	NSA Co MSA } NCo SSA } and Co	NW 5-15 SSA* weak and variable	10+/clear-10/10*	Fog-stratus cloud formation along entire coast.*	2	Sfc	-2	7	69	33	120
Remarks: Synoptic situation same as 23 May, except thermal trough moved westward overlapping coast.						Fog and overcast reported by all coastal stations during day.						

*Occurrence of mesoscale feature discussed in Analysis Results section.

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
18-29 April (continued)												
25	3	Nsh and Co	MSA NW 3-15*	10+/clear-9/10*	Fog-stratus cloud wedge from Pt Reyes southward and spreading over southern half of study area.*	2	Sfc	1	12	73	40	60
	Remarks: Pacific H withdraws westward, thermal trough over California controls air circulation over California coast. Coastal indices at extreme value or beginning reversing (cooling) trend. Ul reflects reduced/calm winds offshore.					Fog and overcast reported by all coastal stations during day.						
26	3	Ofs	Weak and Variable	10+/overcast	Fog-stratus cloud formation over entire study area.	3	Sfc	1	11	69	45	95
	Remarks: Rapid advance of frontal system over northeastern Pacific into study area, passage over central California late in day.					Heavy and light fog at all coastal stations.						
27	4	Co and dissipates late in day	NW 15-20	10+/5/10-9/10	Fog-stratus cloud wedge over coast and inland from Pt Reyes southward spreading over southern study area.	4	470	-1	9	61	55	200
	Remarks: Pacific H moved over northeastern Pacific Ocean (west of Oregon) dominating air circulation along coastal regions.					Fog present at all coastal stations through most of day lifting to overcast late in day.						
28	4	-	NW 20-25	10+/5/10-10/10	X	4	1000	-3	2	53	58	270
	Remarks: Pacific H moving southward, thermal trough over western Nevada cause isobar alignment to parallel coast.					Overcast reported by all coastal stations throughout day.						
29	0	-	NW 25	10+/4/10	X	0	850	-1	-2	58	51	200
	Remarks: Pacific H stationary offshore, controls air circulation over coastal regions, marine layer established over coast.											

* Occurrence of mesoscale feature discussed in Analysis Results section.

APPENDIX D

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

5-19 May 1973

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
5-19	May	1973										
5	4	Co (weak)	=NNW 20	X	X	3	Sfc	-2	-2	x	x	220
	Remarks: Ridge of high pressure orientated NE-SW over Pacific coast extending inland over NW Pac states, isobar alignment meridional over coast, slight surface inversion present over coast due to air flow from inland (Sacramento Valley) regions of northern California.					Overcast most of day at all coastal stations.						
6	4	-	NW 15-25	10+/NSA 4/10	Complete cloud cover over southern half of study area. Frontal system associated cloud band approaching study area from NW.	4	700	-3	-1	x	x	180
	Remarks: Pacific H pushed south as frontal system advances out of northern Pacific Ocean, sfc inversion is lifted to 700 nm and replaced by cooler (marine) air. Isobar alignment parallel to coast.					Clear most of day at all coastal stations.						
7	1	-	NW 10-20	10+/3/10	Study area clear except for small localized low clouds in NSA, patchy coastal fog-stratus.		Isoth to 1000 m	-3	-1	x	x	200
	Remarks: Frontal system passage 0100 left study area relatively clear, Pacific H stationary in EASTPAC, ridge extending NE overlapping NW Pacific States, isobar alignment parallel coast. Intrusion of thermal trough developing over eastern California and Nevada. Fog and overcast reported early morning associated with frontal activity.					Overcast all day at Pillar Pt, mostly clear at other coastal stations.						

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
5-19	May	(continued)										
8	2	Ofs 30 nm	NW 5-10 NSA NW<5	10+/1/10 1 fogger NSA midafternoon <.5 nm/6/10	Appears to be a thin (low) fog-stratus cloud parallel to coast 20-40 nm offshore, clear band near-coast and coastal.	2	Sfc	+1	+3	x	x	140
	Remarks: Pacific H stationary over EASTPAC, advance of frontal system over Oregon and northern California, disturbed coastal air circulation. Frontal passage over study area late in day.					All coastal stations clear.						
9	3	NCo/Co	NW 10-20	1-10 nm/10/10 NSA early morning 10+/5/10 NSA afternoon	Fog-stratus cloud scattered over study area, mostly clear coastal area.	3	300	-1	6	68	34	160
	Remarks: Pacific H displaced further south as result of advance of frontal system moving southward. Early morning fog associated with frontal activity. High pressure ridge extending NE over NW Pacific States behind front result in isobar alignment SSW-NNE over central California.					Early morning fog at Pt Pinos, overcast remainder of day. Pigeon Pt clear all day. Pillar Pt overcast most of day.						
10	2	NCo from Pt Reyes southward*	NW 15-20*	10+/clear-3/10	Entire study area clear however low cloud wedge* formation along coast in lee of Pt.Conception, clear air band south of Pt.Conception.	2	Sfc weak	1 M	10	79 M	80 m	110
	Remarks: Pacific H migrating rapidly to NNE, thermal trough weakly protruding into southern California and southern Nevada. Isobar alignment NE-SW across central California. Coastal indices indicate warm air flow into coastal regions offshore winds strong and NW.					Scattered coastal overcast.						

*Occurrence of mesoscale feature discussed in Analysis Results section.

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status Ph	Loc of CCZ	Ship Data Winds	Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
5-19	May	(continued)										
11	2	NCo from Pt Reyes southward	NSA NNW 15-20 SSA weak/ vari- able or calm	NSA 10+/clear-2/10 SSA 10+/3/10-9/10 2 foggers	Study area clear except for fog-stratus cloud wedge along SSA from Pt Pinos southward.	2	Sfc	0	12	73	44	80 m
	Remarks: Air circulation over central California controlled by thermal trough overlapping California coast. Increased warming over coastal region strengthen surface inversion.					Fog at Pt Pinos 0400 on through the day. Overcast at Monterey Airport.						
12	3	NCo and Co	weak/ vari- able or calm	10+/8/10-10/10	Fog-stratus cloud entire length of coast in study area, clear seaward of 124°W longitude.	3	250	-.3	13	72	40	110
	Remarks: Pacific H developing EASTPAC, thermal trough pushed inland over California. Offshore winds producing weak onshore marine air flow.					Heavy fog and overcast at all coastal stations entire day.						
13	4	Co	NCo NNW 5-10 Co weak or calm	10+/6/10-9/10	Fog-stratus cloud entire length of coast in study area, slight shoreward movement from previous day.	3 4	100	-.3	14	65	44	80
	Remarks: Pacific H pushed southward as frontal system approaches from north Pacific Ocean, thermal trough extends up entire Pacific coast to Washington.					Fog or overcast conditions all day at all coastal stations.						

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Ph	Model Status Loc of CCZ	Ship Data Winds	Ship Data Vis/Ceiling	Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
5-19	May	(continued)										
14	4	Co and inl	NCo NNW10 Co weak or SE10	10+/3/10-9/10	Fog-stratus cloud same as previous day with scattered light (thinning) overcast, more of coastal and inland area covered by fog-stratus cloud.	4	100	.4	12	70	48	60
	Remarks: Ridge of high pressure establish between coast and approaching frontal system west of California coast, thermal trough pushed inland over California, winds along California coast weak and variable.					Mostly overcast with some light fog at all coastal stations.						
15	4	Co and inl	weak/ variable	10+/NSA 3/10	Fog-stratus cloud wedge cover coastal area from Monterey Bay southward, thin fog-stratus cloud covers remainder of study area.	3	350	.4	13	x	44	60
	Remarks: Pacific H close off southern California, high pressure ridge extends northward over entire Pacific coast, approaching frontal system dissipating offshore, thermal trough dissipating over California.					Overcast with some light fog at all coastal stations.						
16	3	Co	NCo NNW <u>15-20</u> NSA Co NNW5	NCo 6-10 nm/10/10	Uniform fog-stratus cloud band 40-50 nm wide extends along entire Pacific coast, thin fog-stratus cloud covers NSA, clear over offshore SSA.	3	Sfc weak	1	10	x	x	105
	Remarks: Pacific H cell covers entire Pacific coast and separates coast and approaching frontal system offshore. Thermal trough extends over inland central California.					Light fog most of day at all coastal stations.						

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
5-19	May	(continued)										
17	3	Entire study area	NNW15	1-10 nm/10/10	Fog-stratus cloud covers entire offshore study area and some coastal areas.	3	200	2	13	x	x	120
	Remarks: Pacific H weakened as frontal system offshore slowly approached the Pacific coast, thermal trough overlapped central and southern California coast.					Heavy fog at all coastal stations most of day.						
18	3	NCo and Co	NNW 5-15	10+/8/10-10/10	Fog-stratus cloud cover entire offshore and coastal study area.	3	180	.5	15	x	x	200
	Remarks: Pacific H moved further offshore, extension of ridge overlapping NW Pacific States, lies in between coast and another approaching frontal system, as previous offshore frontal system advanced inland over Canada. Thermal trough withdrawn southward over western Arizona.					Fog or overcast at all coastal stations entire day.						
19	4	-	NSA NNW 10-20	NSA 10+/4/10	Fog-stratus cloud covers southern half of study area Clear over NSA.	4	500	-2	10	x	x	240
	Remarks: Pacific H dominates air flow over eastern Pacific and steers the frontal system eastward over central and northern California late evening. UI value indicates return of NW winds while other coastal index values remain constant. Inversion base lifts above 400 m, surface air temperature near sea-surface temperature.					Overcast predominates at all coastal stations.						

APPENDIX E

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

22-30 Sep 1973

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
22-30	Sep	1973										
22	0	-	=W 20	NSA 10+/6/10	Frontal system associated cloud formation over study area.	0	650	1	1	71	28	60
	Remarks: Weak low pressure cell and associated frontal system moving eastward over Pacific coast.					Overcast most of day, evening fog associated with frontal passage.						
23	0	-	=NW15	X	Study area mostly clear. Scattered low clouds over coastal area.	1	-	0	1	67	52	100
	Remarks: Pacific H stationary, steering migrating low and associated frontal system eastward over northeastern Pacific Ocean. Isobars aligned NW-SE over central California coast.					Occasional overcast reported by all coastal stations.						
24	0	-	W 5	10+/3/10-9/10	Scattered cloud formation over most of study area. Frontal system associated cloud formation inland over central California.	1	650	1	2	71	x	100
	Remarks: Frontal passage mid-morning over study area, Pacific H establishing air circulation behind frontal system, ridge of high pressure extended northward.											
25	1	Co	MSA NW 20	10+/1/10	Study area clear.	2	Sfc	-.5	1	76	x	80
	Remarks: Pacific H dominates air circulation over EASTPAC ridge extends NE over NW Pacific States, thermal trough extended inland into northern California. Isobar alignment NNE-SSW over central California coast.											
26	2	NCo and Co	SSA SSE10 -calm	X	Study area clear.	2	Sfc	-1	8	80	56	0
	Remarks: Thermal trough overlaps just offshore the California coast and controls air circulation over coastal areas.											

OFFSHORE AND COASTAL DATA ANALYSIS SUMMARY

Offshore Data						Coastal Data (Beardsley, 1976)						
Date	MFD Model Status		Ship Data		Satellite Data	Ph	BI	MI	TI	HHT_M	$HHRH_m$	UI
	Ph	Loc of CCZ	Winds	Vis/Ceiling								
22-30 Sep (continued)												
27	2	NCo	weak and vari- able	10+/clear	Study area clear.	2	Sfc	-3	10	80+	0	0
	Remarks: Synoptic conditions same as 26 Sep.											
28	3	Ofs 15-25nm	=NNW5	X	Fog-stratus cloud band off- shore 15-25 nm, clear air band off coast.	3	Sfc	-.5	12	80+	4	20
	Remarks: Thermal trough weakening and moving inland. Frontal system advancing offshore.					Coastal stations report fog commencing late morning for remainder of day.						
29	3	Ofs-Co	NNW 10-15	6-10 nm/ 9/10-10/10 NSA, 2 foggers	Entire offshore and coastal area covered with fog-stratus cloud formation.	3	Sfc	-1	11	80	16	70
	Remarks: High pressure cell over northern Pacific Ocean dominating air circulation over entire eastern Pacific thermal trough moving inland. Frontal system approaching study area.					Fog reported most of day by all coastal stations, over- cast remainder.						
30	4	Co	weak and vari- able	10+/overcast	Fog-stratus cloud band along entire coast offshore to 123.5°W longitude.	4	400	-2	7	67	44	105
	Remarks: Pacific H moving eastward pushing isobars inland, isobars aligned NNE-SSW over central California. Frontal passage through study area and across coast late morning.					Fog at Pillar Pt most of day overcast remainder of stations most of day.						

LIST OF REFERENCES

1. American Meteorological Society, Weatherwise, surface weather maps from v. 26, No. 2, 3, 4, 5, 6, April-December 1973, and v. 27, No. 1, February 1974.

2. Beardsley, J. W., Fog on the Central California Coast for 1973: Analysis of Trends, M. S. Thesis, Naval Postgraduate School, Monterey, California, March 1976. (Advisor: D. F. Leipper)

3. Edgerton, C. F., "Availability and Credibility of Maritime Visibility Observations", Tech. memo. ML74-004t Visibility Laboratory, Scripps Institution of Oceanography, University of California, San Diego, California, July 1974.

4. Environmental Prediction Research Facility Tech. Note 2-72, Coastal Sea-Air Interactions and the Extent of Coastal Influence, Progress Report 1, April 1972.

5. Fairbridge, R. W., The Encyclopedia of Oceanography, p. 154-156, Reinhold Publishing Corporation, 1966.

6. Hale, R. E., Use of the NOAA-2 Digitized Satellite Data for Diagnosing Marine Fog in the North Pacific Ocean Area, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1975. (Advisor: R. J. Renard)

7. Environmental Prediction Research Facility Tech. Note No. 8, Coastal Sea-Air Interactions and the Extent of Coastal Influence, Progress Report No. 2, by T. Laevastu, November 1973.

8. Leipper, D. F., The Sharp Smog Bank and California Fog Development," Bulletin of the American Meteorological Society, v. 49, No. 4, p. 354-358, April 1968.

9. Leipper, D. F., "Fog Development at San Diego, California," Sears Foundation: Journal of Marine Research, v. VII, No. 3, p. 337-346, November 1948.

10. Lepore, D. J., Naval Weather Service Detachment UNCLASSIFIED Letter 3146, Ser 500/76505 to LT. Steve Evermann, Subject: Surface Marine Observations Data File; Information Concerning, 10 August 1976.

11. McConnell, M. C., Forecasting Marine Fog on the West Coast of the United States Using a Linear Discriminant Analysis Approach, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1975. (Advisor: R. J. Renard)

12. National Marine Fisheries Service (NOAA), Southwest Fisheries Center, La Jolla, California, Fishing Information Supplement, Sea Surface Temperature Diagrams, January-December 1973.

13. Naval Weather Service Command, 1975; U. S. Naval Weather Service Numerical Environmental Products Manual, NAVAIR 50-1G-522, Department of the Navy, Washington, D. C.

14. Naval Weather Service, "Local Area Forecaster's Handbook," Naval Air Station Alameda, California, 1972.

15. Peterson, C. A., Fog Sequences on the Central California Coast with Examples, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1975. (Advisor: D. F. Leipper)

16. Pilie, E. J., and others, The Importance of Organized Vertical Motions in Coastal Fog, paper presented at the American Meteorological Conference on Coastal Meteorology, 21-23 September 1976.

17. Naval Postgraduate School Report NPS-51Rd75041, Climatological Marine-Fog Frequencies Derived from a Synthesis of the Visibility-Weather Group Elements of the Transient-Ship Synoptic Reports, by R. J. Renard, R. E. Englebretson, and J. S. Daughenbaugh, April 1975.

18. Rosenthal, J., Point Mugu Forecaster's Handbook, Pacific Missile Range, Point Mugu, California, April 1972.

19. Schrock, J. A., Transient Ship Synoptic Reports, an Evaluation of their Contributions to a Fog Study of 19 August - 5 September 1974, and 1-5 December 1975, M. S. Thesis, Naval Postgraduate School, Monterey, California, June 1976. (Advisor: G. H. Jung)

20. Schroeder, M. J., and others, "Marine Air Invasion of the Pacific Coast: A Problem Analysis," Bulletin of the American Meteorological Society, v. 48, No. 11, p. 802-808, November 1967.

21. U. S. Departments of Commerce, Defense and Transportation, Federal Meteorological Handbook No. 2, Synoptic Codes, (Also NAVAIR 50-1D-2), Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1969b.

22. Wheeler, S. E., Marine Fog Impact on Naval Operations, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1974.

23. Willms, G. R., A Climatology of Marine-Fog Frequencies for the North Pacific Ocean Summer Fog Season, M. S. Thesis, Naval Postgraduate School, Monterey, California, September 1975.

24. Wright, J. T., Some Observations from a Light Aircraft of the Marine Air Inversion Associated with Low Stratus and Fog Conditions in the Monterey Bay, Department of Meteorology, Naval Postgraduate School, Monterey, California, September 1975.

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